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APPLICATION OF SELECTED INDUSTRIAL ENGINEERING TECHNIQUES TO WASTEWATER TREATMENT PLANTS

Charles W. Mallory, et al

Hittman Associates, Incorporated

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Application of Selected Industrial Engineering Techniques to Wastewater Treatment Plants

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A number of recommendations were offered to develop programs for upgrading wastewater plant management. (EPA)

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APPLICATION OF SELECTED INDUSTRIAL ENGINEERING TECHNIQUES TO WASTEWATER TREATMENT PLANTS

By

Charles W. Mallory

Dr. Robert Waller

Contract No. 14-12-946
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Project Officer

Walter F. McMichael
Environmental Protection Agency
National Environmental Research Center
Cincinnati, Ohio 45268

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ABSTRACT

A study was performed to evaluate the applicability of various industrial engineering techniques to operation and maintenance of secondary waste treatment plants. Numerous techniques used in military and industrial projects were evaluated and applied in a case study at the Flint, Michigan waste treatment plant using actual plant data, practices, and procedures. Emphasis was placed on Work Study and Reliability and Maintainability analysis.

The evaluations indicated that a variety of techniques were directly and beneficially applicable to the development of rational management programs for design, operation, maintenance, staffing, and quality control. An overall approach to develop complete management programs was developed whereby designers or managers could start from effluent goals and rationally develop designs, O & M procedures, and staffing levels as well as increase plant reliability. Quality control programs are hampered by: poor parameters for measuring effluent quality and process control; lack of knowledge on causes of variability of plant effluent quality as well as the nonsteady state effects of equipment failures; the prevailing practices for setting quality goals, collecting and evaluating performance data; and current practices for enforcement of performance requirements by regulatory agencies.

A number of recommendations were offered to develop programs for upgrading wastewater plant management.

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SECTION I

CONCLUSIONS

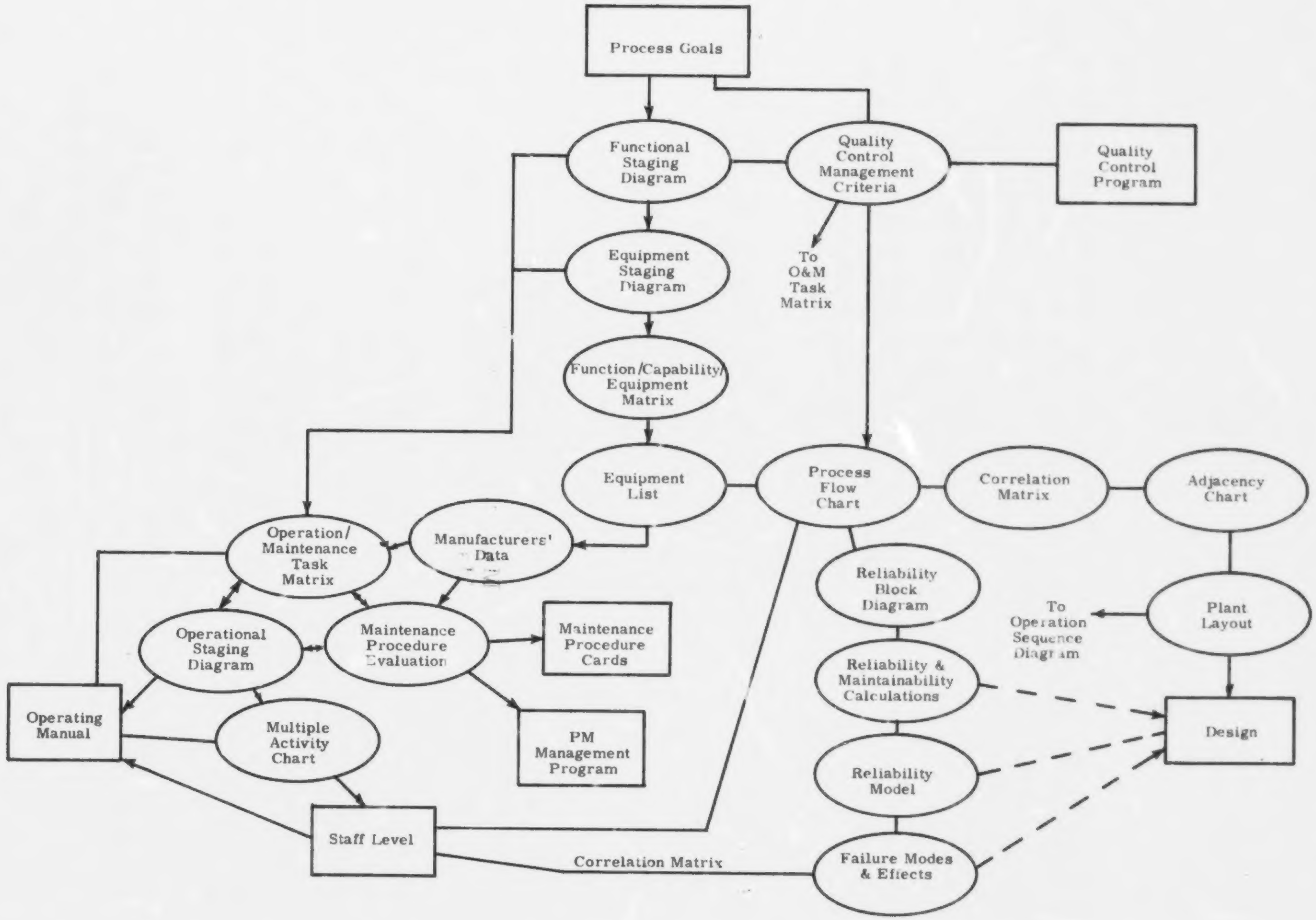
As a result of this study, it was concluded that industrial engineering techniques should be more universally applied in the planning, design, maintenance, operation, and management of wastewater treatment plants. The management programs for wastewater treatment plants are generally deficient in comparison to accepted practices in industry. Although the "Federal Guidelines for Design, Operation, and Maintenance" (Ref. 8) require that facilities have maximum reliability, be capable of operating during certain failure modes, be designed for ease of routine maintenance, have defined operation, maintenance,and staffing requirements, have operation and maintenance manuals, etc., little has been done to guide designers in meeting these requirements.

The industrial engineering techniques used in industry and on military systems are generally applicable to wastewater treatment plants and will provide a rational basis for the planning, design, operation, maintenance, and management of wastewater treatment plants. The objective of this study was to determine the techniques that would be applicable to wastewater treatment plants and to define by illustration how these techniques could be applied. The techniques found to be applicable are summarized in Table 1. The interrelationship of these techniques is graphically illustrated on Figure 1. The principal conclusions from this study are as follows:

> Functional Staging Diagrams, System/Equipment Staging Diagrams, Process Flow Schematics, and Function-Capability-Equipment Matrices should be used in the initial planning and design of wastewater treatment facilities to assure that all of the required functions are provided without unnecessary redundancy and to provide a basis for the selection of equipment (Section V and Appendices A, B, and D).
>
> The use of Correlation Matrices and Adjacency Charts will provide a basis for the development of a plant layout with proper consideration of process flow, minimum pumping and piping, and future operation and maintenance (Section V and Figures 4 and 5).
>
> Operational Sequence Diagrams define man-machine interfaces and provide a basis for the development of operating procedures, operational manuals, training aids, and engineered time standards (Section V and Appendix E).
>
> The System/Equipment Staging Diagrams provide the basis for the development of a Preventive Maintenance System, a Work Order System, Maintenance Work Schedules, and a

TABLE 1. SUMMARY OF INDUSTRIAL ENGINEERING TECHNIQUES APPLICABLE TO WASTE TREATMENT ACTIVITIES

Activity	Applicable Techniques
Design	Functional Staging Diagrams
	System Equipment Staging Diagrams
	Function-Capability-Equipment Matrices
	Indexed Equipment List
	Process Flow Sheet
	Plant Layout
	Correlation Matrix
	Adjacency Chart
	R&M Analysis
Operation	Functional Staging Diagrams
	System Equipment Staging Diagrams
	Operational/Maintenance Task Matrices
	Operation Sequence Diagram
	Plant Layout
Maintenance	System/Equipment Staging Diagram
	Function-Capability-Equipment Matrices
	Indexed Equipment List
	Operational/Maintenance Task Matrices
	Maintenance Procedure Cards
	R&M Analysis
Staffing	Operational/Maintenance Task Matrices
	Operation Sequence Diagrams
	Multiple Activity Chart
	Maintenance-oriented Techniques (see above)
	Operations-oriented Techniques (see above)
	R&M Analysis
Quality Control	Application of Effective Management Principles
	Process Flow Sheet
	Reliability and Maintainability Calculations



Process Goals
Functional Staging Diagram
Quality Control Management Criteria
Quality Control Program
Equipment Staging Diagram
To O&M Task Matrix
Function/Capability/ Equipment Matrix
Equipment List
Process Flow Chart
Correlation Matrix
Adjacency Chart
Operation/ Maintenance Task Matrix
Manufacturers' Data
Reliability Block Diagram
Plant Layout
To Operation Sequence Diagram
Operational Staging Diagram
Maintenance Procedure Evaluation
Maintenance Procedure Cards
Reliability & Maintainability Calculations
Operating Manual
Multiple Activity Chart
PM Management Program
Design
Reliability Model
Staff Level
Correlation Matrix
Failure Modes & Effects

Figure 1

Interrelationships Between Industrial Engineering Techniques

Maintenance Reporting System. The Maintenance Procedure Evaluation Sheets, Standard-Time Tables, and Preventive Maintenance Ratio can be used in the planning and evaluation of maintenance functions (Section VI).

Operational/Maintenance Task Matrices and Multiple Activity Charts can be developed from the Operational Sequence Diagrams to provide a basis for determing and defining optimal staffing and skill levels for wastewater treatment plants (Section VII).

The application of Process Control to wastewater treatment plants is limited due to the lack of on-line instrumentation to determine the character of the incoming wastes, the limited technology on the factors that cause the variability of wastewater treatment processes, and the time required for the analysis of the quality of effluent samples (Section VIII).

Based on present technology and analytical equipment, process control of the biological treatment process is generally limited to the control of the food (BOD) to microorganisms ratio (recycle sludge) based on flow measurements (Section VIII).

Reliability and Maintainability Evaluation Techniques provide a quantitative basis for designing wastewater treatment systems, sizing and selecting equipment, and defining the requirements for redundant subsystems and components to assure maximum on-line availability (Section IX).

Because of the limited knowledge of the biological treatment process with respect to the effect of various failure modes, it is not possible to quantitively define the relationship between effluent quality and equipment reliability; however, Failure Mode-Effects Analysis Techniques can be applied to define qualitative relationships (Section IX).

Industrial engineering techniques should be particularly valuable in the planning, design, operation, and maintenance of advanced wastewater treatment process since no precedent exists for the operation and staffing of these systems. Process Control and Reliability and Maintainability Evaluation Techniques can be applied to these systems better than biological treatment systems because the process parameters are more predictable (Section X).

This study was based on the Sewage Treatment Plant located at the City of Flint, Michigan. A summary of the typical specific benefits that might be derived through the use of industrial engineering techniques at this plant and other wastewater treatment plants are as follows:

If Functional Staging had been applied in the design of the original plant, certain of the equipment provided to permit alternative operating modes could have been eliminated.

The use of a Correlation Matrix and Adjacency Chart could have changed the plant layout to more effectively group operating functions.

The System/Equipment Staging Diagrams prepared for this study can now be used to develop a Preventive Maintenance System and cost accounting and maintenance control systems.

The Operational Sequencing Diagram prepared for this study will provide a basis for the preparation of standard operating procedures and for training new personnel.

The Preventive Maintenance Ratio for the Flint Plant indicates that additional personnel on preventive maintenance, particularly in the electrical equipment area, would reduce the need for corrective maintenance and repair.

The Multiple Activity Charts for the Flint Plant indicate that the operating personnel will be able to handle more preventive maintenance tasks during their shifts.

The Operational/Maintenance Task Matrices prepared for the Flint Plant will provide a basis for assigning lower level skill jobs to personnel during in-service training.

The Flint Plant controls the recycle sludge based on incoming flow to control the food-to-microorganism ratio and the process control is undoubtedly a major factor in the high removal efficiencies attained by this plant.

The reliability and maintainability analysis of the Flint plant has indicated a number of areas where equipment reliability can be improved.

The results of the reliability and maintainability analysis can also be used to establish stock levels for repair parts and frequency of preventive maintenance for the various equipment.

The greatest overall benefits that will be attained through the use of industrial engineering techniques will be assurance of a higher probability of successful operation and more effective removal of pollutants. In many cases, the application of these techniques may cost more in terms of personnel, spare parts, and redundant systems. By the use of industrial engineering techniques, it will be possible to assure maximum return on investment in terms of performance.

SECTION II

RECOMMENDATIONS

This report covers a survey of industrial engineering techniques and illustrates how certain techniques can be applied to wastewater treatment plants. This report is not intended to be a standard to be explicitly followed in the planning, design, and operation of wastewater treatment plants. The purpose of this report is to introduce wastewater treatment managers and designers to the industrial engineering techniques and to provide guidance to industrial engineers on how selected techniques might be applied to wastewater treatment plants. From this initial effort, it is hoped that a closer interdisciplinary relationship can be developed among sanitary, environmental, civil, and mechanical engineers; wastewater treatment plant planners, managers, and operators; and industrial engineers. A number of projects should be undertaken by the Environmental Protection Agency to facilitate the application of industrial engineering techniques into the planning, design, operation, and maintenance of wastewater treatment plants. The recommended projects are as follows:

> A manual on the "Operational and Maintenance Aspects of Wastewater Treatment Plant Planning and Design" should be prepared. This would provide standard guidelines to be used to factor industrial engineering techniques into wastewater treatment plants. This would include procedures for developing and applying each of the techniques previously listed in Table 1.
>
> Either as a part of the manual or as a separate project, standardized Functional Staging Diagrams, Equipment Staging Diagrams, and Function-Capability-Equipment Matrices should be developed for a variety of secondary wastewater treatment processes. These could be made part of the construction grant application and would serve as a checklist to assure completeness and as an index for the later development of operation and maintenance packages.
>
> As a part of the construction of a new wastewater treatment plant, a special grant could be made to have industrial engineering techniques applied starting in the planning stage and continued through construction and operation. Special reports covering this aspect would provide valuable guidance to others and would foster the further application of these techniques in the wastewater treatment field.
>
> A program should be initiated as soon as possible for the systematic collection of failure, reliability, and maintenance data on wastewater treatment plant components. These data will provide a basis for implementing reliability and maintainability evaluations as part of wastewater treatment plant design and will provide criteria for better specifying components.

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An experimental program should be undertaken to develop a better understanding of the effects of various types of failures on biological treatment processes. This technology will be needed to relate equipment reliability to effluent quality and to set standards for more effective treatment processes.

An experimental program should be initiated to investigate the causes of variability in effluent quality with biological wastewater treatment processes and to define quantitative relationships which describe nonsteady-state conditions and effects. This technology is a prerequisite to further development of process controls, automated control, and quality control of biological wastewater treatment processes.

A state-of-the-art study of on-line process control techniques should be undertaken to define the requirements for control and analytical equipment and the characteristics of presently available equipment. Deficiencies will be identified which would be the subject of development programs.

A review should be made of the requirements of various states on the reporting of effluent water quality data and wastewater treatment plant performance data. The objective of this project is to determine the practicality and advisability of having uniform reporting requirements by regulatory agencies and better standards for quality control.

Specific recommendations for the Flint Plant and a further discussion of some of the overall recommendations are contained in Section XI.

SECTION III

INTRODUCTION

BACKGROUND

Over the past decade, several billion dollars have been spent at the local, state, and federal levels on wastewater collection and treatment systems. Indications are that additional expenditures over the next few decades will be perhaps an order of magnitude greater. These massive expenditures are being made for the avowed purpose of upgrading and protecting the quality of the nation's waterways; however, the emphasis on funding has been almost exclusively aimed at the construction of facilities. The effectiveness of any facility, conventional or advanced, is largely determined by the operation and maintenance policies employed. Unfortunately, wastewater treatment operating policies have largely evolved through trial and error and are often unrelated to actual system capabilities and independent of process selection.

Recent actions by EPA and its predecessor agencies have attempted to establish a stronger link between plant design, equipment specifications, and operating considerations by including specific requirements in the "Federal Guidelines for the Design, Operation, and Maintenance of Wastewater Treatment Facilities" issued September 1970. The "Guidelines" call for an analysis of operational requirements, staffing requirements, consideration of reliability, ease of maintenance, adequate operating records, an effective maintenance program, and an operation and maintenance manual. However, little or no information exists in the literature to guide a designer or manager in the satisfaction of these requirements.

Considerable advancement has been made in the application of industrial engineering techniques to integrate the technical, operational, and human factors involved in the operation of complex systems. These techniques have been refined and improved through long use in industrial, military, and aerospace systems. The systematic application of industrial engineering analysis can result in the development of more effective and efficient operating policies, improved maintenance procedures, measurement of and improvement in plant reliability, maintenance criteria for the design and specification of process equipment, and staffing requirements by skill level for each unit process.

This project was concerned with the application of selected industrial engineering techniques to the operation and maintenance of wastewater treatment plants. Its aim was to evaluate and identify those techniques which could be applied, either immediately or after further work, to the development of sound operation and maintenance practices. To this end, wastewater treatment plants have been considered as manufacturing facilities with sewage as the basic raw material and treated effluent as the finished product.

The following subsections define and describe the industrial engineering techniques considered in this program as well as present the general procedures employed during the course of the study.

INDUSTRIAL ENGINEERING TECHNIQUES

Methods Engineering or Work Study

The terms "Methods Engineering" or "Work Study" are used to describe a collection of analysis techniques used to improve the effectiveness of men and machines. It enables the industrial engineer or manager to subject each phase of an operation to systematic analysis. Methods Engineering or Work Study engineering is a combination of industrial engineering work measurement, method study, human factor, and management techniques combined with system engineering function analysis, synthesis, evaluation, decision-making, and design techniques. It was developed to simultaneously apply the advantages of industrial and system engineering techniques to the efficient and effective design and improvement of systems in which functions are performed by men and equipment. Its basic approach is to collect meaningful data on complex systems and to arrange the data in a form whereby evaluation, innovation, and implementation are more easily performed.

Many of the techniques were first developed by Frederick W. Taylor at the end of the 19th century. Frank and Lillian Gilbreth pioneered motion study and applied the techniques to the design of efficient work areas and factory layouts. At the same time, Charles E. Bedaux improved the methods of measuring work elements, and in the 1930's the concept of Work Study was set forth by Russell Currie of England; World War II provided the necessary opportunities to perfect the industrial engineering techniques of modern Work Study. In applying Work Study techniques, a "problem" is a man-machine design which must be defined, an operation and maintenance system which must be developed, an estimate of personnel staffing required, etc.; it is a situation requiring logical and systematic analysis to determine specific resources necessary to accomplish the required functions of a system. The eight steps of Work Study are:

Problem Definition	(1) Select:	Clearly define the objectives, the scope, and the depth of the study.
	(2) Record:	Gather and record accurate and complete facts (data) required.
	(3) Examine:	Carefully and critically analyze the facts.

Problem Solution	(4) Innovate:	Generate a variety of alternatives which might provide the best solution to the problem.
	(5) Evaluate:	Analyze the alternatives using pertinent criteria and determine the best alternative(s).
	(6) Develop:	Determine and describe procedural steps necessary to place the best alternative(s) in operation.
Execute as Approved by Management	(7) Install:	Provide assistance required to initiate procedural operations.
Feedback from System	(8) Maintain:	Monitor operations and make appropriate adjustments which may be required.

The engineer, in conducting Work Study, should be objective and investigate all alternatives in order to arrive at the most acceptable problem solution. Critical examination requires answers to the questions: WHAT?, WHEN?, WHO?, WHY?, and HOW?, and is essential to eliminating the unnecessary. The final result is a logical, practical, well-documented solution to the problem studied.

For an existing plant, on-site recording by the engineer is essential to insure a factual basis for his subsequent analysis. Photographs are taken of facilities and equipment pertinent to the study, and other information and data are collected. Operational procedures are documented, as required, so that the engineer will have a complete description and understanding of how the system under study is operating and is supposed to operate. Basic analytical descriptions, such as operational sequence and flow diagrams and flow process and multiple activity charts, are initiated during the recording phase to insure that all pertinent information is obtained and to facilitate subsequent analysis. Quite often, such description and analysis techniques must be specially adapted for the system studied to pinpoint the unique features of its dynamic operations. Examples and actual applications of these techniques are given in later sections.

Functional Staging Diagram (FSD)

The Functional Staging Diagram is the backbone of the Work Study techniques applied in this program. It is a block diagram structure which is used to determine and display the interdependency of functions necessary for a system to operate. It is developed vertically from its top block, which identifies the goal function downward through lower horizontal levels of blocks. Each array of blocks at a lower level contains descriptions of "how" the functions to which they are connected by lines at the next higher level are accomplished. That is, the lower staged functions are required to be performed in order that the related function at the next higher stage may be satisfied. This approach breaks down and organizes complex functions into smaller, more manageable elements. A simple example of an FSD is given in Figure 2.

Functional Staging Diagrams can be used to organize both operational and maintenance functions into a suitable display for functional analysis. The diagram starts in the top block with a description of the objective to be attained by system operation and extends downward to lower levels. Two-part phrases, a demonstrable verb and a measurable direct object, are used to precisely describe each function to be satisfied including those to be accomplished by equipment and personnel. Functions are numerically coded so that associated data, information, and equipment can be cross-referenced to them during the course of the study. This numerical index is used in many of the succeeding techniques.

Function-Capability-Equipment Matrix

The Function-Capability-Equipment Matrix is used to establish preliminary design characteristics of a complex system. The matrix permits the design engineer to methodically set forth the required or desired capability for each function and subfunction that must be performed to accomplish the system objectives. These functions can be derived from the FSD described above; the use of the same numerical index system aids in cross-referencing and information retrieval. Capabilities are stated in quantitative or definitive terms. Once the capabilities for a specific function have been defined, then the selection of the subsystem or equipment is facilitated. That is, specific equipment is selected to perform the function with the stated (required) capability. The defining of capabilities for a specific function logically leads to the establishment of capabilities for the subfunctions at the lower levels. Function-Capability-Equipment Matrices, when fully developed, establish a basic structure upon which the system designer can visually display total system design capabilities and upon which he can develop an equipment list. In addition, the matrices serve as design checklists to insure that all required functions are met.

System/Equipment Staging Diagram (ESD)

The major purpose of this technique is to provide a visual display and organization around which a system, such as a wastewater treatment plant, can be structured. System configuration, that is, the cataloging of equipment within a system or subsystem, is facilitated by the use of the previously discussed Functional Staging Diagrams, but for this use, the staging diagrams are system/equipment oriented rather than functionally oriented. The system staging diagrams provide the framework to which all the subsystems and equipment can be cataloged. An index number, if possible the same numeric designation as used for indexing the related functional staging element, is assigned to each equipment, subsystem, and system to provide for identification, inventory, sort, audit, and sequencing, either by manual or computer process.

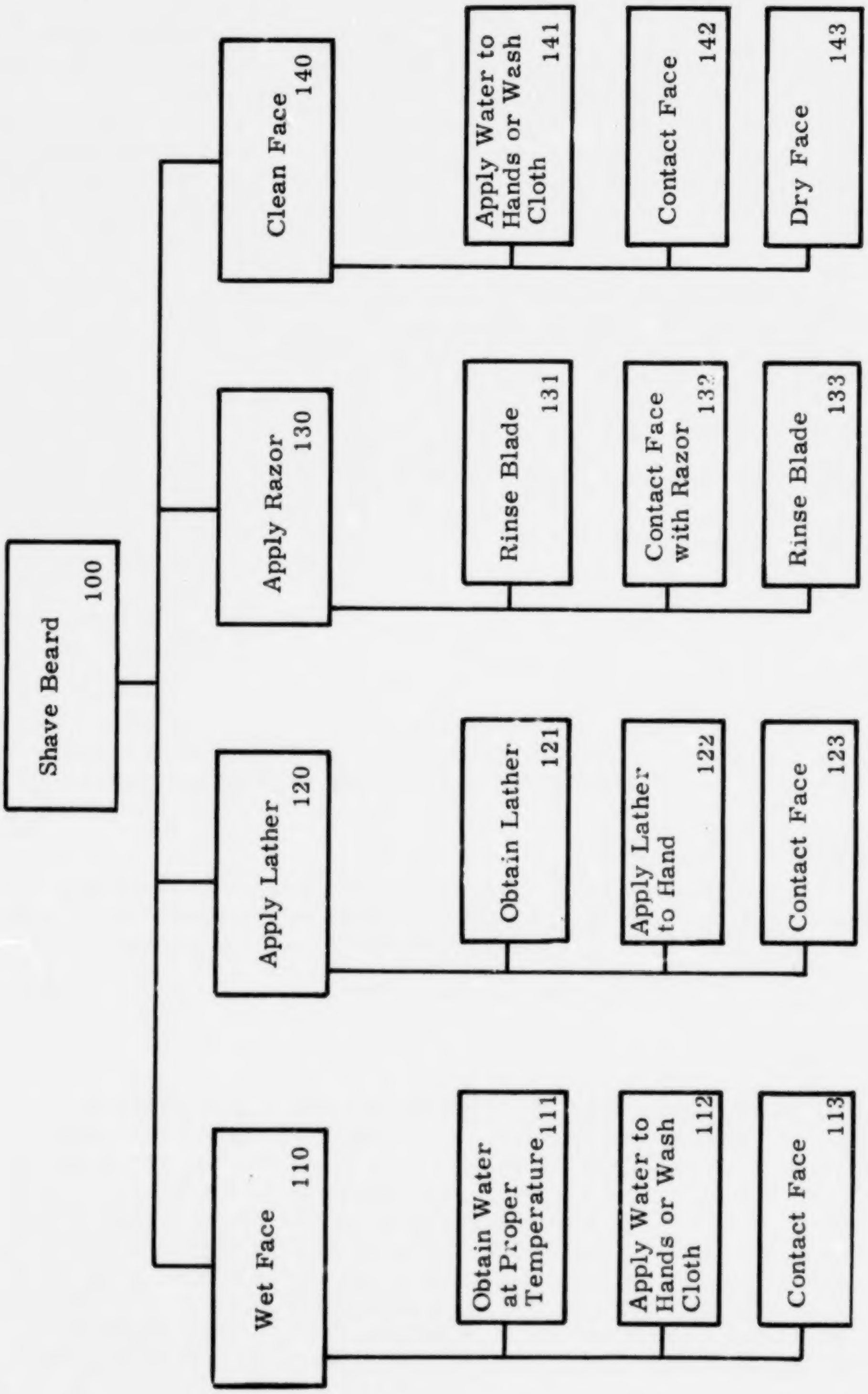
Shave Beard 100
Wet Face 110
Apply Lather 120
Apply Razor 130
Clean Face 140
Obtain Water at Proper Temperature 111
Apply Water to Hands or Wash Cloth 112
Contact Face 113
Obtain Lather 121
Apply Lather to Hand 122
Contact Face 123
Rinse Blade 131
Contact Face with Razor 132
Rinse Blade 133
Apply Water to Hands or Wash Cloth 141
Contact Face 142
Dry Face 143

Figure 2
Example of Functional Staging Diagram

Operational Sequence Diagram (OSD)

The operational sequence diagram displays the information-decision-action relationships within a highly complex system. It is a technique of plotting, relative to time (actual or sequential), the flow of information, data, or energy through an operationally defined system using standard symbols to relate to actions taken (inspections, data transmittal, data receipt, data storage, or decisions) as that data, information, or energy is manipulated internally in the system. A standard set of symbols, established in 1947 by the American Society of Mechanical Engineers (ASME), is used for displaying how functions are performed and for determining:

Man-machine relationships

Equipment requirements

Personnel requirements

Communication requirements

Space-adjacency requirements

Most effective arrangements

Skill levels

Performance times

By plotting the sequence of various operations, the analyst can more readily comprehend and evaluate the mechanics of the various activities.

Multiple Activity Chart (MAC)

A Multiple Activity Chart (MAC) visually displays a time comparison of the activities of two or more men (with or without equipment). Activity descriptions are recorded in a columnar format on a time scale. The MAC is useful in analyzing scheduling problems, work load balance, and manpower utilization. (Figure 10, Section VII, is an example of an MAC.)

Correlation Chart

This technique relates functions of men and equipment in a system by plotting identical functions of men and equipment on both the abscissa and ordinate of a matrix forming a square array. Since the array forms two mirror-like triangles, the common practice is to list only the elements on the ordinate. Relationships and dependencies are coded and recorded within the array based on information, data, or energy flow, or other related factors. This array allows for the grouping and arranging of related factors to facilitate the process flow within the system. Correlation Charts are best used to summarize and display the flow relationships shown in either functional or operational sequence diagrams from which the transition to functional groupings or equipment arrangements can easily be made. (A Correlation Chart is shown as Figure 4, Section V.)

Adjacency Chart

With interrelationships summarized by the Correlation Chart, the next step is the design layout of the system complex or the work space. The Adjacency Chart is a technique to initially develop the design layout. The man or the functional unit with the greatest number of relationships is placed in a central location on the layout sheet. Working from this man, function, or equipment, a relative layout plan can be systematically developed by adding each element related to that man, function, or equipment and to each other. In establishing the placement of the elements, the degree of relationship or adjacency requirements between elements is considered and the elements placed accordingly. (An Adjacency Chart is shown as Figure 5, Section V.)

Critical Examination (CE) Analysis

A time-proven Work Study tool for resolving specific problem areas is the Critical Examination Analysis Sheet. Critical Examination is used to examine recorded data. Recording of the WHAT, WHEN, WHO, and HOW of a work system without further inquiry presupposes that work must be done: WHAT is done; WHEN it is done; WHERE it is done; WHO or WHAT does it; and HOW it is done. When the analyst has answered these questions, he reorients his thinking toward a conceptual line of inquiry that begins with the question, Why? The Critical Examination Analysis Sheet permits the analyst to systematically dissect a specific problem to answer this question of WHY by determining the CAUSE and NEED. Once the CAUSE and NEED are determined, the analyst can then methodically investigate whether the element can be eliminated, modified, or accomplished by other means or methods.

Reliability Techniques

Reliability evaluation is a technology for the analysis, prediction, and counteraction of system failures and their frequency of occurrence. It involves system analysis, function synthesis, equipment design, time degradation of equipment, and system performance. Its primary objectives are attainment of acceptable system performance for needed periods of time and minimum costs for operation and maintenance.

Knowing the types of failures to which a system is prone and the intervals at which they can be expected is invaluable in taking action to prevent failures and thereby avoid an interruption in system operation. Further, this information can provide a sound basis for determining material and personnel resources necessary to support sustained, successful system service.

The following basic definitions or descriptions are pertinent to the evaluation techniques. (The first three are adaptations of those in Military Standard MIL-STD-721, Ref. 1.)

Reliability. Reliability is the probability that a unit (i.e., equipment, subsystem, plant, etc.) will perform its intended function for a specified length of time under stated conditions. The value frequently used to indicate unit reliability is MTBF (mean time between failures).

Maintainability. Maintainability is the characteristic of the design and installation of a system which is a measure of the ease and rapidity with which a plant unit can be restored to an operational condition following a failure. The characteristic MTTR (mean time to repair) is frequently used to indicate unit maintainability.

Availability. Availability is the fraction of operating time a unit is capable of operation. The expression of availability, A, is the interrelationship of reliability and maintainability:

$$\frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

Reliability Model. The initial technique normally used in reliability evaluations is preparation of a model. A model includes a block diagram displaying the dependency of system components whose operations are necessary for minimum acceptable system performance. The diagram also displays additional components which are available or are needed to replace other components which fail. A model includes numerical values which are calculated to indicate the reliability of each component and the system. A reliability model provides the basis for analyzing the reliability of a system and its components during typical system operations. The analysis may also include interrelationship of reliability, maintainability, and availability.

Data Collection and Analysis. To provide numerical information for reliability modelling, data on component operational or test performance must be collected and analyzed; typically, these data are not readily available. Two types of data are required: the number of equipment failures which have occurred during a particular time period, and the amount of time the equipment has been operated during the same time period. Sources of these data vary, but are usually found in maintenance records, equipment operating logs, and manufacturers' customer service files. Data must be carefully reviewed to assure applicability to the equipment being analyzed.

Failure Modes and Effects Analysis. To determine action which must be taken to correct a system reliability problem the potential modes of a failure and their effect on system operation are carefully examined. The results of this examination are used to develop and evaluate various alternatives for improving system reliability by selecting more reliable equipment, providing a duplicate or "standby" unit, modifying the equipment to improve its reliability, or compensating for its failure characteristics through maintenance. The results of this analysis provide a rationale for modifications to system design or an investment in material and personnel resources to reduce failures and preserve the system process.

Maintainability Evaluation Techniques

Maintainability evaluation concerns the analysis of maintenance activity and resources required to return an inoperative system component to its specified operating capability. Its primary objectives are to reduce repair time, facilitate maintenance work, insure conditions of safety for maintenance personnel, and minimize maintenance costs. Although many calculation procedures used in maintainability engineering are directed toward reducing the time required for corrective maintenance, the technology can also be applied to preventive maintenance requirements.

Maintainability Assessment. A Maintainability Assessment is normally performed using information from the reliability model and averages of time typically required to return equipment to an operable condition. Model information is used to determine how often maintenance is required on equipment and the repair times determine how long the equipment will be out of operation. The objective of the assessment is to identify maintenance conditions which are unacceptable in supporting the overall performance of a system.

Data elements used for maintainability assessments are normally in the form of equipment failure rates and mean times to repair (MTTR). Repair times are usually derived from maintenance records and estimates or measurement of times required to perform maintenance task increments.

Maintenance Engineering Analysis

The results from maintainability assessments are used to analyze in detail the resources needed for properly supporting a system when it is in operation. The following are the types of considerations made during this analysis: the frequency and scope of preventive and corrective maintenance required; accessibility to parts which typically require replacement; work space necessary for maintenance activities; methods for reducing the time needed to diagnose and repair failures; and required maintenance resources such as replacement parts and facilities. Results of this analysis are used in formulating a realistic plan for maintaining a system.

Other Techniques

In addition to techniques described above, a number of other industrial engineering techniques can also be applied to wastewater treatment plants. These would include operational analysis, work sampling, time standards, methods time measurement, maintenance standards, work simplification, statistical and regression analysis, incentives, plus cost controls. Within the scope of this project, it was not possible to show how every industrial engineering technique might be applied in the wastewater treatment field. Accordingly, the majority of the effort was concentrated on those techniques which have been successfully used to directly relate operational, maintenance, and management considerations to the physical plant of relatively complex process systems. By using this approach, it was hoped to develop a foundation to which more refined techniques could be added later.

PROJECT APPROACH

As mentioned previously, the basic premise employed in the project was the analogy between wastewater treatment and a "typical" manufacturing facility. Obviously, certain aspects of the analogy are weak, such as market considerations and profitability. However, wastewater treatment plants apply men and machines to raw materials (sewage, air) to produce a product (treated effluent) and a by-product (sludge). On that basis, one can examine design, application, maintenance, and quality control from an industrial engineering point of view.

The initial phase of the project involved the consideration of wastewater treatment plants in terms of systems, subsystems, etc., and the identification of the current approaches to the various functions which lead to design construction and operation. At the same time, a wide variety of Work Study and reliability and maintainability (R&M) techniques, as well as other industrial engineering techniques, were evaluated as to basic applicability to wastewater treatment plants. From this effort, suitable techniques were selected for study. These techniques were applied to an existing plant at Flint, Michigan, to evaluate their applicability in depth and to determine in qualitative terms the degree of difficulty in their application.

It could be agreed that the utility of the techniques could be better demonstrated for a plant under design since the Flint plant had, through trial and error, developed a comparatively good operation and maintenance program. However, the time span between the commencement of design and the starting of a new plant was judged excessive in relation to the desired length of the study program.

Several man-weeks were spent at the Flint plant collecting data from plans, specifications, and personnel. Selected Work Study and R&M techniques were used to organize, synthesize, interrelate, and display the data as well as to evaluate procedures and innovate and develop new approaches. Most of this latter work was performed in the post-data-collection phase. Figure 3 shows the general program flow sheet.

Section IV describes the approach in more detail as well as presents data on the Flint plant. Sections V, VI, VII, and VIII present the results of studies on the application of Work Study techniques on design, operations,

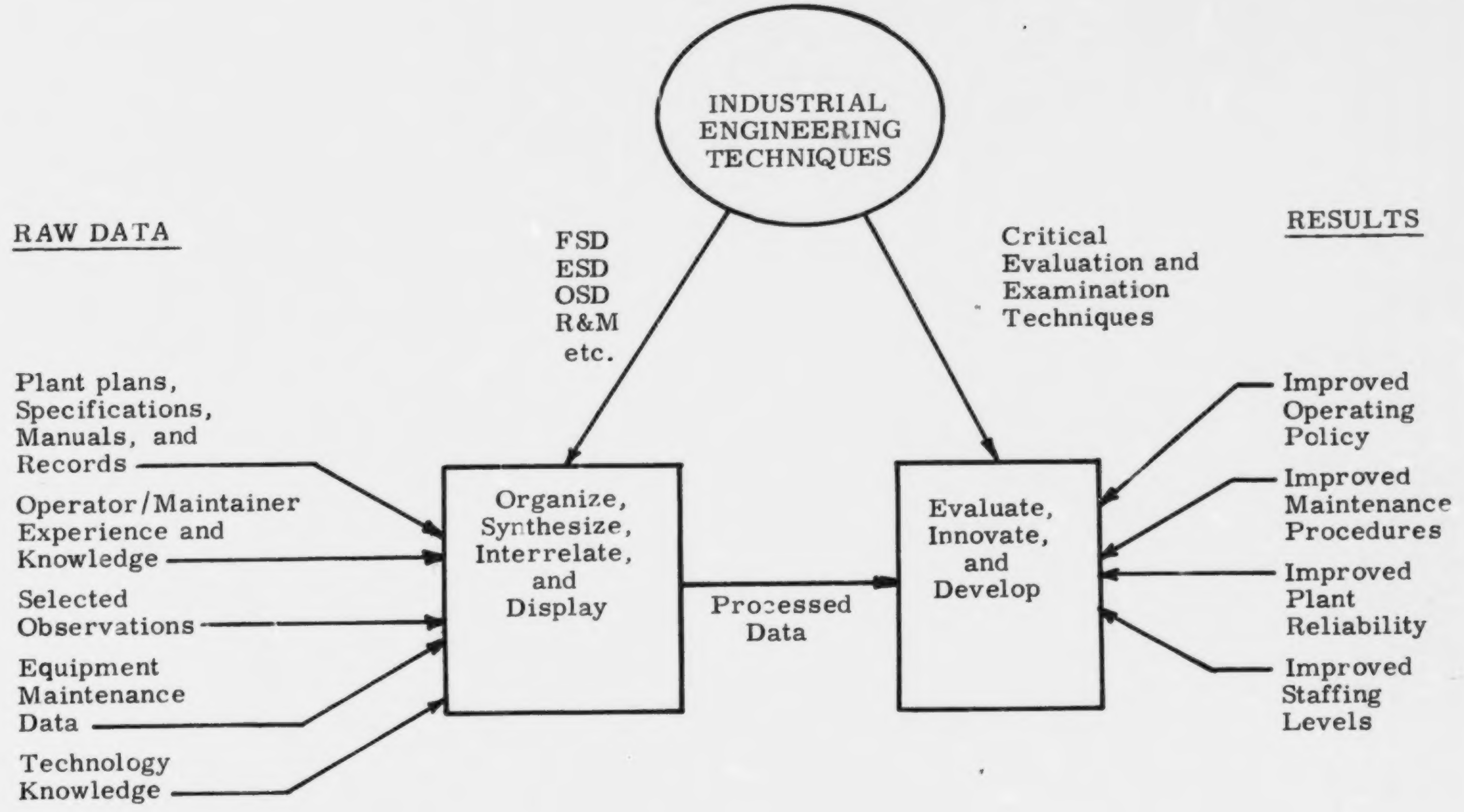
INDUSTRIAL ENGINEERING TECHNIQUES
RAW DATA
FSD
ESD
OSD
R&M
etc.
Critical Evaluation and Examination Techniques
RESULTS
Plant plans, Specifications, Manuals, and Records
Operator/Maintainer Experience and Knowledge
Selected Observations
Equipment Maintenance Data
Technology Knowledge
Organize, Synthesize, Interrelate, and Display
Processed Data
Evaluate, Innovate, and Develop
Improved Operating Policy
Improved Maintenance Procedures
Improved Plant Reliability
Improved Staffing Levels

Figure 3
Program Flowsheet

maintenance, staffing, and quality control. Section IX deals with the applications of R&M analyses including the Reliability Model. Section X discusses the potential application to advanced wastewater treatment systems. A summary discussion, conclusions, and recommendations are presented in Section XI.

SECTION IV

CASE STUDY OF A SECONDARY TREATMENT PLANT

PRERECORDING PHASE

The objectives of the case study phase of the program were to obtain and develop operational and maintenance data, using various Work Study techniques at a selected conventional wastewater treatment plant; to evaluate these data, also using Work Study techniques; and to identify specific improvement areas. Inherent in this objective was the identification of those industrial engineering (Work Study) techniques which could be applied to conventional wastewater treatment plants to achieve improvement of plant performance. To meet these objectives, it was necessary to perform certain preparatory tasks prior to visiting a wastewater treatment plant, including:

Selection of the industrial management areas to be studied

Establishment of the criteria for each industrial management area

Determination of the industrial engineering (Work Study) techniques to be used and evaluated during the on-site data collection phase

Selection of the conventional wastewater treatment plant at which these Work Study techniques could be applied and evaluated

Development of selected Work Study documents and data recording forms which would facilitate the on-site recording process

Selection of the Industrial Management Areas

The four industrial management areas which were deemed of greatest importance to existing wastewater treatment plants were:

Operations

Maintenance

Staffing

Quality Control

Design considerations must be added to be above list for new plants. Since the case study was performed on an existing plant, design functions were indirectly considered.

Establishment of Criteria

The criteria for evaluating each of the four management areas were documented to establish the "yardstick" upon which the evaluation of the case study wastewater treatment plant could be accomplished. They are addressed in detail in Sections V, VI, VII , and VIII . The criteria, which are based upon accepted industrial engineering practices, were obtained from a number of technical publications, the most significant being:

> Handbook of Industrial Engineering and Management, Edited by W. Grant Ireson and Eugene L. Grant (Reference 2)
>
> Industrial Engineering Handbook, Edited by H. B. Maynard (Reference 3)
>
> Production Handbook, Edited by Gordon B. Carson (Reference 4)
>
> Maintenance Engineering Handbook, Edited by L. C. Morrow (Reference 5)
>
> Design Manual, Civil Engineering, NAVFAC DM-5 Naval Facilities Engineering Command (Reference 6)
>
> Operation of Wastewater Treatment Plants, Manual No. 11, Water Pollution Control Federation (Reference 7)
>
> "Federal Guidelines for Design, Operation, and Maintenance of Waste Water Treatment Facilities," Sept., 1970 (Reference 8)
>
> Quality Control Handbook, Edited by J. M. Juran (Reference 9)

Determination of Industrial Engineering (Work Study) Techniques

Having established the "yardstick" factors for wastewater treatment system analysis, the next task was to select from the multitude of industrial engineering techniques those which offered the greatest potential for developing improved operating and maintenance policies or guidelines for all wastewater treatment plants. In selecting these techniques, emphasis was placed on choosing those that would best record data and facilitate analysis of the recorded data to evaluate an existing wastewater treatment plant using the established criteria. Consideration was also given to the fact that the selected techniques might ultimately be used by architects and engineers in the design and staffing of new plants. The selected techniques are discussed under each Industrial Management area in Sections V, VI, VII , and VIII.

Selection of the Conventional Wastewater Treatment Plant

In selecting the conventional wastewater treatment plant for the on-site survey of operation and maintenance, the following factors were the major considerations:

> Should be representative of a large percentage of plants in the United States. A capacity of between 10 and 100 MGD was considered to be desirable.
>
> Processes should include as a minimum primary treatment, secondary treatment, sludge treatment, and disposal and disinfection subsystems.
>
> Age of plant should be 5-10 years in order to possess stability of operation and still have processes of modern design.
>
> Operating under fairly stringent state or local standards of effluent quality.
>
> Considered by state authorities to be a plant operating at near-design capacity and having earned the reputation of being well managed in both the operation and maintenance areas.
>
> State and local government authorities and plant management be agreeable to contractor personnel conducting the on-site survey.

An extensive search was conducted to locate a wastewater treatment plant which satisfied these factors. Several candidate plants were found from which the Sewage Treatment Plant of the City of Flint, Michigan, was selected as meeting all of the previously mentioned factors. A brief description of the Flint plant is contained in subsequent paragraphs.

Development of Selected Work Study Documents and Data Recording Forms

During the prerecording phase, preliminary Functional Staging Diagrams (FSD's) were developed wherein the various wastewater treatment processes known to exist at the Flint plant were staged down to that level at which equipment items normally perform the required functions. These preliminary FSD's were subsequently validated and corrected during the recording phase. The final version of these Functional Staging Diagrams is included in this report as Appendix A. A questionnaire concerning all phases of the operation of wastewater treatment plant was developed as a guide for conducting interviews of plant personnel. Specific examples of Work Study tools were prepared and assembled into a package for use in briefing plant management personnel on the initial day of the on-site survey. Several other standard recording forms such as equipment inventory, flow process charts, Operational Sequencing Diagrams, reliability and maintainability data, etc., were prepared. Some of these forms were used only to record data, the data subsequently being recompiled for inclusion in this report.

DESCRIPTION OF THE FLINT, MICHIGAN, SEWAGE TREATMENT PLANT

The Flint Sewage Treatment Plant is located in the center of a 134-acre site, 2-1/2 miles west of the city limits, adjacent to the Flint River, into which the final effluent flows. The plant, originally constructed in 1926, was modernized and expanded during the period 1953-56 and again during the period 1962-64 when a major expansion was accomplished. The plant serves Flint, Michigan, an industrial city with a population of about 194,000, as well as several surrounding suburban areas. It is primarily an automobile manufacturing city, with industries such as auto assembly plants, auto body works, spark plug manufacturers, paint factories, and foundries.

The plant incorporates a complete activated sludge system plus a complete trickling filter system, both of which receive influent from a common primary system with common waste solids treatment and disposal by filtration and incineration. The trickling filter system was installed as a part of the original plant in 1926 and the activated sludge system was added during the 1962-64 modernization. A Process Flow Schematic and a general Plant Layout diagram are contained in Appendices B and C, respectively. A brief description of the plant facilities follow.

Basic Design Data

Design population	270,000
Design average flow	
Activated sludge	20 million gallons per day
Trickling filter	14 million gallons per day
Anticipated BOD removal	over 90%
Expected removal of organic solids at design flow	60,000 pounds per day
Capacity of incinerators	90,000 pounds per day

Major Process Elements

Influent Box. A raw sewage influent structure establishes the hydraulic head by receiving flow from the Third Avenue Pumping Station and the Northwest Pumping Station. The liquid level is maintained at an elevation sufficient to provide gravity flow from this point through the primary tanks, aeration tanks, final clarifiers, and chlorine contact chamber to the receiving Flint River. The Third Avenue Pumping Station is not an integral part of the plant. Since the Northwest Pumping Station is located in close proximity to the plant proper, it is included as a part of the plant's operation.

Grit Chambers. The sewage passes from the influent structure through a venturi tube to two aerated grit chambers. The chamber size provides a detention period of 2.8 minutes at the average design flow of 34 MGD. These tanks have hopper units from which the grit can be pumped as a slurry to the ash and grit lagoon. However, this latter feature is inoperative and grit is removed manually.

Screening Chamber. The degritted sewage flows from the grit chambers through one of four 36-inch comminutors for screening and cutting of coarse sewage matter.

Primary Settling Tanks. Sewage flows from the screening chambers to six primary settling tanks. Each tank is 41.5 feet wide, 142 feet long, with a liquid depth of eight feet. The combined volume of 272,000 ft^3 (2,034,500 gallons) provides a detention time of 1.43 hours and a surface settling rate of 1000 gallons/ft^2/day at the design flow rate of 34 MGD.

Each tank is equipped with straight-line longitudinal and cross collecting sludge scraping mechanisms which scrape the settled solids to sludge hoppers at the ends of the tanks and skim floating material to revolving type scum troughs near the outlet end. Sludge is withdrawn from the hopper and may be pumped: (a) to the digesters, (b) directly to the vacuum filters and incinerator, or (c) to the sludge thickener building. Effluent from each primary tank flows over V-notched weirs through a Parshall flume for flow measurement.

Distribution of Primary Effluent. The flow of primary effluent is split so that the major portion (approximately 60 percent) goes into the activated sludge process aeration tanks and the smaller flow (approximately 40 percent) to the trickling filters. The latter portion passes through a flow meter and enters the settled sewage wet well. This wet well also receives a portion of the trickling filter effluent that is recirculated; the mixture of settled raw sewage, plus recirculated filter effluent, is pumped from the wet well to the trickling filters.

Trickling Filters. Each of the two fixed nozzle trickling filters, with concrete dosing tanks, has a filter area of 3.8 acres. These are currently operated with a hydraulic loading of 3 million gallons per acre per day and an organic loading of 240 pounds BOD per acre-foot per day.

Final Settling Tanks (After Trickling Filters). Two final settling tanks have a capacity of 22.6 MGD. Humus sludge is normally pumped to the sludge-thickening building. However, it also can be pumped to the primary tanks or to the digesters.

Chlorine Contact Tanks - Trickling Filters. The final effluent from the trickling filters passes to four chlorine contact tanks. The total volume of these tanks is 68,000 ft^3 and provide over one hour detention.

Activated Sludge Aeration Tanks. The piping and valve arrangements, meters, and controls allow the use of:

> Conventional activated sludge process (normal mode of operation)
>
> Step-aeration activated sludge
>
> Krause-Nitrification modification of activated sludge

Three aeration tank units, each consisting of four passes, are equipped with swing type air diffusers using Saran-wrapped tubes. To control froth formation, a series of spray nozzles (using final effluent) are located at the walls opposite those at which diffused air is supplied. The total 750,000 ft^3 volume provides a five-hour detention time at a sewage flow of 22 MGD, plus 25 percent return sludge rate.

Blower Building. This structure houses three centrifugal single-stage, electric motor driven air blowers. These blowers are sized to produce a variable air output ranging from 15,000 cfm to 30,000 cfm. Space is provided for a future additional blower. Normally, one blower is in operation.

Asbestos-coated bag air filters are provided ahead of the blowers with sufficient capacity to handle maximum air load to the blowers.

Final Settling Tanks. Discharge from the aeration tanks flows in a channel to three final settling tanks providing a total volume of 354,672 ft^3. At design flow, the detention time is 1.78 hours, with a surface settling rate of 1241 gal/ft^2/day.

Settled sludge is withdrawn through a sludge collector and sent to a sludge well from which it is possible to pump return sludge to both the aeration tanks and to waste. Waste sludge from the activated sludge system can be sent to the sludge thickening building or returned to the primary tanks.

Final Effluent Aeration Facilities. In order to provide additional oxygen in the treated flow before discharge to the Flint River during the periods of critical dissolved oxygen content in the reach below the treatment plant, a postaeration tank is provided to oxygenate the plant effluent before chlorination. The location of this tank is adjacent to the aeration tanks. Air is introduced in a manner similar to that used in the aeration tanks; about 10 minutes detention time is provided.

Chlorination Facilities - Activated Sludge. A chlorination contact tank, located next to the postaeration tank, provides 20 minutes detention at design flow.

Two chlorine feed machines, each with a capacity of 2000 pounds per day, are provided and equipped with evaporators, scales, and alarm.

Chlorine solution may be applied through diffuser units located at the following points:

Plant influent structure (raw sewage)

Settled sewage wet well prior to trickling filters

Aeration tanks - return sludge entrance

Final effluent chlorine contact tank

Sludge Concentration. In order to decrease the capacity required in sludge digesters and avoid the difficulties encountered in settling trickling filter humus and waste activated sludge, a flotation-thickening process has been installed using pressurized primary effluent mixed with the sludge being thickened.

Three tanks are housed in the sludge thickening building. Also contained therein are pumps, piping, valves, meters, and appurtenances. Provisions are made to thicken primary sludge and skimmings when required.

This process has successfully thickened 400 gpm of waste activated sludge at 0.9 percent solids to 4+ percent using 1200 gpm of pressurized primary effluent to provide flotation bubbles. The thickened sludge may be pumped to the digesters or sent directly to the incinerators. The subnatant is discharged to the activated sludge aerators for secondary treatment.

Sludge Digestion Storage Tanks. Three 80-foot diameter floating cover digesters with exterior heat exchangers, meters, and controls originally designed to provide a 30-day detention time at design loading of 43,700 pounds of sludge solids per day are currently utilized for storage of sludge. The digesters are not operated in the conventional manner; i.e., sludge digestion.

A gas storage sphere originally installed to collect sewage gas for use in the digester sludge heat exchangers or the sludge incinerators is not utilized.

Sludge Dewatering Facilities. Digester sludge, raw sludge, or a mixture of the two may be pumped to an aerated 18,000-gallon sludge well at the vacuum filter building. The sludge is pumped from this well with variable speed pumps to a chemical conditioning tank adjacent to each of three vacuum filters. These filters are equipped with coil springs as filter media. Each filter has 360 ft^2 area, providing a capacity of 1440 pounds per hour dry solids when operating at 4 $lb/ft^2/hr$.

Equipment for the automatic unloading, storing, handling, slaking, and feeding of lime to the sludge prior to vacuum filtration is provided. A rubber lined storage vat, capacity 6000 gallons, is provided (inside) for ferric chloride solution brought in by truck. Studies have been made to investigate the improvement filterability by the use of polyelectrolytes.

Filtered sludge cake is conveyed on belts from the vacuum filters to the incinerators. A bypass facility is provided to allow for the conveying of sludge cake to trucks during emergencies.

Sludge Incineration. There are two 6-hearth furnaces, each having a capacity of evaporating 6500 pounds of water per hour and burning 2200 pounds of dry solids per hour.

Exhaust gases pass through wet scrubbers, using plant final effluent. The water leaving the scrubbers drops into the ash hopper for quenching the incinerator ash. The ash slurry is pumped to the ash and grit lagoon continuously.

Administration Building. This building houses offices, a conference room, laboratory, master meter-control room, employees kitchen, lunchroom, and washrooms.

Service Building. The original administration building has been remodeled into a machine and general repair shop, including garage, spare parts storage, and maintenance supervisor's office.

Recently, the Michigan Water Resources Commission issued new effluent criteria for the plant which limit the BOD_5 discharged to 3300 pounds per day, NH_3-N to no more than 0.5 mg/ℓ, 80 percent P reduction and a maximum suspended solids content of 35 mg/ℓ. In addition, the plant is to be expanded to an average design flow of 50 MGD. Thus, the treatment plant will be undergoing considerable change in the next few years.

RECORDING PHASE

A detailed on-site survey of the operation and maintenance of the Sewage Treatment Plant at Flint, Michigan, was conducted in April 1971, with two additional visits in May and July 1971. Almost 40 man-days were spent conducting this survey. The following activities were performed:

> Previously developed Functional Staging Diagrams and System/Equipment Staging Diagrams were validated and appropriate changes, additions, and deletions made to reflect special conditions at Flint.
>
> A preliminary Equipment Inventory List was prepared based upon the System/Equipment Staging Diagram. This inventory was compared to the fragmentary equipment lists available at Flint and data collected from plant inspection. From this process, the System/Equipment Staging Diagram and the Equipment Inventory List were revalidated. The updated Functional Staging Diagram and the System/Equipment Staging Diagram are given in Appendices A and D, respectively.
>
> Based upon review of plans, inspection, and interviews with plant personnel, a process flow schematic (Appendix B) and a sketch of the physical layout of the plant (Appendix C) were prepared.
>
> A personnel list, organization, and staffing data, including skill level, were collected from relevant plant documents and plant management.
>
> Data on operator maintenance and maintenance staff functions were recorded from interviews with plant personnel and inspection of plant records.
>
> Operational Sequencing Diagrams (OSD's) were developed for the four principal operating positions: foreman, primary operator, filter operator, and furnace operator (Appendix E). These were prepared by observing and recording operator's movements and activities followed by post-recording interviews to note deviations. The OSD's included the recording of type and frequency of inspections and samplings conducted by the operators. Also included were several of the normal and nonroutine activities that occur on an unscheduled basis but are critical to successful operation. It was necessary in some cases to obtain the OSD data by interviewing the operator because the activity of interest did not occur during the data collection phase (for example, a power failure).

Copies of inspection, sampling, preventive maintenance action, and other recording forms were obtained and were included in the review. The completion of these forms establishes the activity pattern of the staff to a large degree.

The operator equipment malfunction logs for the six-month period October 1970 through March 1971 were reviewed to determine those equipment failures or malfunctions which affected the plant's operation and consequently were data inputs for the reliability and maintainability calculations.

Key personnel, including the Plant Supervisor, Assistant Plant Supervisor, and the Plant Maintenance Supervisor, were extensively interviewed regarding the various aspects of the operation and maintenance performance of the plant.

Monthly operating reports of the type submitted to the State of Michigan were reviewed and used as part of the process control and quality control evaluation.

POST-RECORDING PHASE

Each of the four management areas previously described was studied as an entity. The data recorded at the Flint Plant were reviewed, evaluated, and, in many instances, were reorganized to facilitate evaluation for the specific industrial management area studied.

Additional Work Study techniques such as multiple activity charts, adjacency charts, correlation charts, etc., were prepared to assist in evaluation. Each technique selected was carefully studied to ensure that its application for the intended task was proper. It should be noted that the major value of the Work Study techniques employed is that they organize and display data in such a manner that evaluation is simplified. In almost every case, no new data, such as a mathematical parameter, are developed. The purpose is to organize and display so that evaluation and innovation can be facilitated. Thus, the major portion of the post-recording phase involved:

Evaluating the basic utility of the Work Study techniques applied

Repetitive refinement of the data as understanding of the complex interrelationships in the plant process increased

Consideration of the data as displayed and organized by the Work Study techniques in relation to specific criteria

Identification of potential areas where improvements could be made

Evaluating the effects that these potential improvements could have

Developing and evaluating various methods of enhancing the utility of the Work Study techniques

The evaluations, including "yardstick" criteria, the findings, and the recommendations for each of the four industrial management areas are described in detail in Sections V, VI, VII, and VIII. In addition, considerations of the application of these techniques to the design of new plants are given in Section V.

SECTION V

EVALUATION OF WORK STUDY TECHNIQUES ON OPERATIONAL ACTIVITIES

In the context of this section, the operational aspects of waste treatment include the major factors which determine or influence the ability of the treatment plant to satisfactorily perform its function. Strictly speaking, this would include almost all activities that one normally associates with waste treatment including maintenance, staffing level, etc. However, this section is confined to consideration of process planning or preliminary design, plant layout, operational procedures, and plant flexibility. Later sections will deal with maintenance, staffing, and quality control, all of which certainly have an influence on operations.

The following discussion includes a consideration of the criteria for success for each of the operational activities, both in the context of classical industrial engineering and as governed by waste treatment requirements, along with a brief discussion of current general waste treatment practice. This is followed by a discussion of the industrial engineering techniques that were applied in each area as well as an evaluation as to their utility. Finally, conclusions and recommendations are presented on the applicability of the techniques employed.

CRITERIA

Process Planning

In designing or planning a process system, the objectives, in terms of product goals, are the baseline from which all process planning develops. For any manufacturing installation, the product requirements must be clearly stated and understood. Process planning, or preliminary design, is the translation of product goals into an effective and efficient assemblage of equipment arranged for optimal operation and maintenance. Normally, it is an iterative process where the basic equipment elements are first developed and the final design evolves from a series of trade-offs between capital and operating costs. Thus, the process planning procedure should be closely tied to product goals and should provide means for consideration of other aspects of plant activities such as operating procedures, maintenance, etc.

Currently, the definition of product goals for waste treatment plants can, at best, be characterized as variable. In almost every case, the State regulatory agency, the "customer," sets the required product characteristics. However, a problem exists in that between states these requirements are neither consistent nor complete. This is not to suggest that all waste treatment plants should have the same effluent quality. Some states specify "secondary treatment" as a process requirement with the implication that the effluent will be of that quality normally

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associated with secondary treatment, whatever that may be. Others set effluent standards in terms of an allowable concentration of certain quality parameters (BOD, suspended solids, etc.). Still others state their product goals in terms of a maximum amount of a constituent in terms of pounds per day that can be discharged based upon knowledge of the receiving stream. This diversity results in a wide variety of design procedure practices. Another aspect of the setting of process goals is the large variability inherent in the biological treatment process. Studies (Refs. 10, 11) have shown that the coefficient of variation of quality parameters increases through the treatment plant. That is, there is more variability in the BOD content around the mean of treated effluent than in the upstream steps. One would have intuitively expected the opposite to be true, given the dampening effect of tankage involved of about 10 hours total detention in conventional activated sludge plants with primary and secondary clarifiers. On the other hand, the dynamics of biological treatment under the normal daily or hourly variations in critical process parameters (inflow rates, BOD, suspended solids, etc.) are poorly understood. This, coupled with a lack of suitable monitoring instruments, contributes to an inability to exert close control over the process.

Given these uncertainties, it is not surprising that in many instances the biological treatment plants merely involve the satisfaction of equipment design criteria, such as overflow rates for clarifiers, aeration tank detention time, etc. This approach would fulfill the "secondary treatment" requirement. In other cases, pilot or bench scale plant tests are run to determine the product quality achievable in terms of the amount or concentration of pollutant. In very few cases is the question of variability addressed since it is almost never required by the regulatory agencies.

Layout

The spatial arrangement of the equipment in a manufacturing process is important from the standpoint of product flow and ease of operation and maintenance. In wastewater plants, a primary factor in determining layout is the topography as it relates to hydraulic design, including flow rates, location of pipes, safety, plant expansion, etc. This subject is adequately covered in several standard environmental engineering texts and consequently will not be dealt with in this report. However, once the topographic considerations are satisfied, there are layout decisions to be made which may be susceptible to industrial engineering analysis. For example, one significant criterion is the minimization of the length of piping and the number of bends to minimize plugging, particularly in the sludge handling systems.

Procedures

If a plant is to produce an acceptable product, the equipment must be operated in the proper manner. Operating procedures can be divided into routine, normal nonroutine, and emergency. In many manufacturing operations, routine operations are highly repetitive. Standard operating procedures have been developed after careful study to maximize productivity.

Wastewater plants differ somewhat from most manufacturing facilities due to the variability of the raw material (sewage). In order to be effective, the operators of a wastewater treatment plant, particularly the supervisory personnel, should have a thorough knowledge of the functions of each unit in the plant, how each unit accomplishes its function, how to evaluate the operation of each unit, and how each unit fits into the overall plant process. The operators should be thoroughly familiar with the general theory and practice of the operations of the plant and be familiar with the characteristics of the wastewater to be treated including changes in flow patterns, organic and solids loadings, industrial wastes, etc. They should also be familiar with local, state, and federal requirements which set the standards for the treatment process. This latter item necessitates the keeping of process records to facilitate appropriate reporting on a periodic basis to regulatory authorities.

In order to ensure consistent performance the plant should have standard operating procedures for normal, nonroutine, and emergency operations. These operating procedures should include inspection and sample collecting check-off lists to ensure standardization and uniformity of actions by the various shift operators. Finally, it is essential that the plant have an active training program for the operators which enhances not only more efficient operations but offers advancement incentives for all grades of personnel, from trainee up to supervisory positions.

In most cases, operating procedures have been developed by trial and error with certain basic operating functions known at startup. Few plants have standard operating procedures. Recently EPA, through the "Federal Guidelines for Design, Operation and Maintenance of Wastewater Treatment Facilities," 1970 (Ref. 8) has required an operating manual to be prepared for new federally-assisted plants. In the past, few plants were equipped with a comprehensive and detailed operating manual. Historically, most manuals prepared were concerned with how each equipment group is operated rather than how the operator functions.

Flexibility

The design of process piping, equipment arrangement, and unit structures must allow for efficiency and convenience in operation and maintenance and provide maximum flexibility of operation. Such flexibility should permit the highest possible degree of treatment to be obtained under varying circumstances. Since plant operation is a 24-hour-a-day, seven-day-a-week, 52-week-a-year operation, redundancy of certain key units or equipment is mandatory. In other cases, unit bypasses may suffice. Provisions should be designed into the systems for removing the duplicate units from service separately.

APPLIED INDUSTRIAL ENGINEERING TECHNIQUES

During the course of the study, several industrial engineering (Work Study) techniques were applied. Initially, these techniques were applied as discrete units; i.e., independent of an overall analysis of a given aspect of the plant's functions. Upon evaluation, however, it became apparent that several techniques were applicable to the operational aspects of wastewater treatment. These are briefly described below.

Functional Staging

Functional Staging Diagrams (FSD's),contained herein as Appendix A, were developed to methodically document the functions and subfunctions which a conventional wastewater treatment plant is required to perform to satisfy the objectives established for primary, secondary, and sludge treatment processes. They were originally prepared in the prerecording phase for general application and then refined to meet conditions at Flint. These FSD's were the basis for subsequent development of Equipment Staging Diagrams, Function-Capability-Equipment Matrices, and the Reliability Block Diagrams.

Process Flow Schematic

A Process Flow Schematic for the Flint Sewage Treatment Plant, shown in Appendix B, was developed by recording the process systems. Ideally, process flow planning is best accomplished during the conceptual planning stage in conjunction with the selection of systems and equipment. Apparently, the design engineer did use such a process diagram to develop the detailed plans and specifications. However, such a diagram covering the total plant was not available to the recording team.

Physical Plant Layout

An existing Plant Layout Diagram provided by the Flint Plant Supervisor was agumented to include amplifying data. The diagram is included as Appendix C. This diagram was used in conjunction with the Process Flow Schematic to evaluate adjacency of equipment requirements.

System/Equipment Staging Diagrams

The Functional Staging Diagrams were used to develop System/Equipment Staging Diagrams, contained herein as Appendix D. Systems and subsystems required to perform the stated functions were documented using the corresponding index number from the FSD to permit the user to identify the functions associated with the particular system or subsystem. The lower stages of the FSD's were used to determine the type of equipment required to perform the functions of the various subsystems with the equipment grouped under each subsystem. The System/Equipment Diagrams were used as a check-off list to establish an Equipment Inventory List for the Flint Plant. This inventory list was used to evaluate the maintenance system and to develop the reliability and maintainability calculations. Entries in the list were made according to the numerical index developed in the FSD. To illustrate the complexity of a sewage plant, over 250 different equipment entries were required, not counting multiple or redundant units and subassemblies such as motors, drivers, etc.

Operational Sequence Diagrams (OSD's)

The Flint plant is organized such that routine operations are conducted, under the direct supervision of the Plant Supervisor and the Assistant Supervisor, by three equally manned shifts, each shift consisting of a Foreman, a Primary Operator, a Filter Operator, and a Furnace Operator. The routine is such that, with minor exceptions, the inspections, taking of samples, recording operational data, and normal operating tasks are the same for each shift. Check-off and recording forms are provided each operator to ensure that specific inspections, samplings, and data recordings are made at prescribed times (hourly, every two hours, twice a shift, once a shift, etc.). Each operator and the foreman were observed performing their duties and their actions recorded on at least two occasions and Operational Sequence Diagrams (OSD's) were prepared to visually display their actions. The OSD's, contained in Appendix E, were used, together with additional information concerning nonroutine and emergency procedures gained by interviews of key personnel, to evaluate the operational and maintenance requirements of the various plant processes. The OSD's were also used to develop data for analyzing personnel requirements.

Correlation Matrix and Adjacency Chart

A Correlation Matrix and Adjacency Chart were developed and are shown in Figures 4 and 5, respectively, to demonstrate how a design engineer might use the techniques during the preliminary design phase to determine arrangement of process units in a plant or to determine arrangement of equipment within a space. As indicated in Figure 4, the various process units are rated relative to their closeness requirements to other units. The reason for the selected rating value is also shown by code. The Adjacency Chart was used to evaluate the layout of the existing Flint plant.

The equipment groupings in the Correlation Matrix are arranged according to normal process flow. For any equipment grouping, the importance of proximity to the other groupings that follow in the process is found by reading downward the most right-hand column for that equipment group.

Function-Capability-Equipment Matrix

To demonstrate another technique which a design engineer might use during the preliminary design phase, a Function-Capability-Equipment Matrix, shown in Figure 6 for the Flint plant, was developed for the selected function, "Receive Sewage and Remove a Large Portion of Settleable and Floating Solids (1100)," from the Functional Staging Diagram. This matrix defines the capabilities required to perform the

INFLUENT BOX	↴																
GRIT CHAMBER	A 1 & 2	↴															
COMMINUTOR	D 3 & 4	A 1 & 2	↴														
PRIMARY TANKS	I 3 & 4	I 3 & 4	A 1 & 2	↴													
AERATION TANKS	D 3 & 4	D 3 & 4	N	A 1 & 2	↴												
ACTIVATED SLUDGE CLARIFIERS	N	N	N	N	A 1 & 2	↴											
CHLORINATION CONTACT TANK	N	N	N	N	N	A 1 & 2	↴										
SLUDGE . WELL	N	N	N	A 1 & 2	A 1 & 2	A 1 & 2	N	↴									
BLOWERS	N	N	N	N	A 3 & 4	N	N	N	↴								
DIGESTERS	N	N	N	N	N	N	N	A 3 & 4	N	↴							
THICKENERS	N	N	N	N	N	N	N	A 3 & 4	N	A 3 & 4	↴						
THICKENED SLUDGE WELL	N	N	N	N	N	N	N	D 3	N	A 3 & 4	A 1 & 3	↴					
CHEMICAL CONDITIONERS	N	N	N	N	N	N	N	N	N	N	A 3 & 4	A 1 & 3	↴				
VACUUM FILTERS	N	N	N	N	N	N	N	N	N	N	N	I 1 & 3	A 1 & 2	↴			
INCINERATORS	N	N	N	N	N	N	N	N	N	N	N	N	N	A 1 & 3	↴		
ASH LAGOON	N	D 1 & 4	N	N	N	N	N	N	N	N	N	N	N	N	A 1 & 3	↴	
RIVER	∿∿∿	N	N	N	N	N	A 1 & 2	N	N	N	N	N	N	N	N	N	↴

CLOSENESS VALUE

≣	A	ABSOLUTELY NECESSARY
≡	I	IMPORTANT
—	D	DESIRABLE
	N	NOT IMPORTANT
∿∿∿	U	UNDESIRABLE

REASON CODE

1	SEQUENCE
2	GRAVITY FLOW
3	MINIMUM PIPING
4	LINEARITY

Figure 4
Correlation Matrix

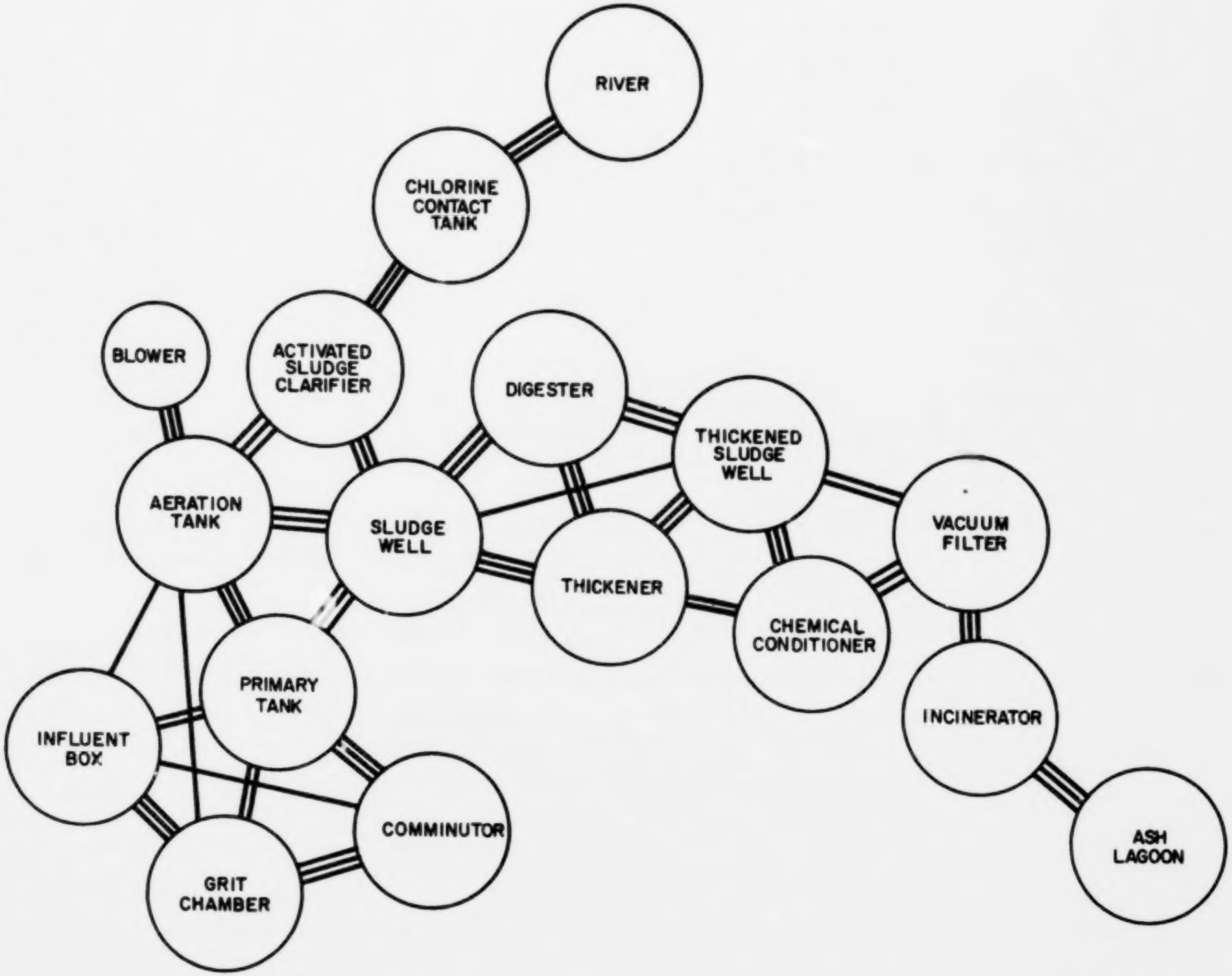

RIVER
CHLORINE CONTACT TANK
BLOWER
ACTIVATED SLUDGE CLARIFIER
DIGESTER
THICKENED SLUDGE WELL
AERATION TANK
SLUDGE WELL
VACUUM FILTER
THICKENER
CHEMICAL CONDITIONER
PRIMARY TANK
INFLUENT BOX
INCINERATOR
COMMINUTOR
ASH LAGOON
GRIT CHAMBER

Figure 5

Adjacency Chart (Excludes Trickling Filter

INDEX NO.	FUNCTION	REQUIRED CAPABILITY		SYSTEM/EQUIPMENT
11000	Receive sewage and remove a large portion of settleable and floating solids	Provide capability to receive and treat raw sewage of the following characteristics:		Primary Treatment Subsystem
		Total daily flow rate	34.0 MGD	
		BOD loading	59, 500 lbs/day	
		Suspended solids	59, 500 lbs/day	
		Remove settleable and floating solids as follows:		
		BOD	30%	
		Suspended Solids	60%	
11400	Remove settleable and floatable solids	Remove organic loadings as follows:		Primary Clarifier Element
		BOD	17, 850 lbs/day	
		Suspended Solids	35, 700 lbs/day	
11410	Receive and Contain Wastes for Settling	Provide:		
		Overflow Rate	1000 gal/ft^2/day	Settling Tanks 6 - Tanks, 41.5' x 142' x 8' 6 - Weirs, 378 ft.
11420	Collect settled solids	Provide capability to remove approx. 6000 lbs of sludge per day per tank		12 - Flight Mechanisms 6 - Sludge Wells (one each tank)

Figure 6

Function-Capability-Equipment Matrix

specified function for the specific plant being designed. The general concept of the technique is to define the required capabilities for each of the functions and subfunctions in the functional staging document to facilitate the selection of the system or equipment required to perform that function or subfunction. The matrix technique is a methodical and systematic approach to documenting the total capability requirements of the system and thus creating a structure to establish system design requirements and to establish a preliminary equipment list for that system.

Reliability Model

The Reliability Model and associated reliability and maintainability analysis data documents are discussed in Section IX. Mention of the model is made only to indicate that it is an industrial engineering technique applicable to operational aspects of wastewater treatment systems.

FINDINGS

Process Planning

Because the case study was performed on an existing plant, it was not possible to relate the results of the application of Work Study techniques to the design process for the Flint Plant. However, several techniques which were developed for use in studying existing plant activities appear to be quite useful for the preliminary design of new plants. These include: Functional Staging Diagrams, System/Equipment Staging, Process Flow Schematics, and the Function-Capability-Equipment Matrices. The use of these techniques provides a logical rationale for the development of an equipment list in which the entries are cross-indexed to required functions.

The FSD can be a very useful tool in that it identifies all functions that must be satisfied before equipment selection. Thus it acts as a checklist for the designer to ensure completeness of his design. This is particularly useful where innovative processes are being developed. In addition, the FSD could serve as a checklist for the regulatory agency to ensure that the critical functions are being met.

By using the Function-Equipment-Capability matrix, the design decisions regarding the satisfaction of required functions are clearly identified. The design data are organized in a form that is easily extracted for reports or specifications and facilitates review by regulatory agencies for technical adequacy. Knowing the required function and capability permits the designer to evaluate alternative equipment or designs by comparing performance characteristics against the required capability. By using the same index system as the FSD's, the equipment designated in the above matrix is automatically keyed into functions and can be readily grouped into subsystems. Alternatively, the designer can choose a more convenient grouping and formulate a new index system. The important factor is that an index system is generated to facilitate subsequent operation and maintenance management.

The process flow sheet and plant layout obviously assist the designer in determining the relationships between elements in the overall system. In most cases, these documents have been prepared to varying degrees of detail.

One industrial engineering concept which has been poorly handled in the waste treatment design is the setting of product quality goals. At the present time, there are great discrepancies between requirements which lead to a variety of design approaches. If the operational aspects of biological waste treatment are to be elevated to a science, there must be much more definitive and consistent effluent quality requirements, requirements that are based not only on stream conditions, but also upon knowledge of the inherent variability of biological treatment plant performance. Until this latter information is developed, there is little basis for attributing variations in effluent quality to design inadequacies, operator or equipment failure, or inherent variability.

The degree of difficulty in applying the above techniques to process planning was not directly measured since they were applied at an existing plant. Except for the FSD, the techniques involve similar efforts in collection of data and design decisions as currently practiced. The main difference is in the organizational format. The preparation of the FSD's represented a novel approach to consideration of treatment systems. However, standard FSD's could be developed for use by designers.

Layout

In establishing the layout of the plant and the equipment within a space in that plant during the detailed design phase, two industrial engineering techniques can be applied:

Plant Layout Diagram

Correlation Matrix and Adjacency Chart

Although Plant Layout Diagrams are generally applied by design engineers, the development of such layouts warrants discussion. The Correlation Matrices together with the associated Adjacency Chart are effective tools to determine the optimized layout or arrangement of units and equipment. The technique can be applied to total systems such as demonstrated in Figures 4 and 5 to subsystems, or to rooms where arrangement of equipment and controls is critical. The technique permits the design engineer to determine the relative location of units or equipment to each other. It is extremely useful in translating the man-equipment relationship into operational arrangements of equipment controls.

Evaluation of the layout of the Sewage Treatment Plant at Flint by comparing the plant layout shown in Appendix B with the Adjacency Chart, Figure 5, indicated that the Thickened Sludge Well, Chemical Conditioner, Vacuum Filter, and Incinerator units would be more effectively located closer to the Sludge Well, Digester, and Thickener units. This finding is substantiated by the numerous malfunctions of the piping systems between the thickener-digester building complex and the incinerator building due to plugged lines. It is reasoned that if the units involved were closer together, the shorter length of piping runs and the reduction of the number of bends would have reduced the number of malfunctions significantly.

It should be possible to develop generalized system Adjacency Charts for use in design guidelines. Current design manuals make little mention of subsystem location. The charts could be very advantageously used by designers to display dependencies of equipment groups within buildings or areas.

Procedures

In the development of operational procedures and training of the operators of wastewater treatment systems, five industrial engineering techniques can be applied. These are:

Operational Sequencing Diagrams

Functional Staging Diagrams

Equipment Staging Diagrams

Process Flow Schematics

Function-Capability-Equipment Matrix

The Operational Sequencing Diagrams (OSD's) proved to be an effective tool to record the activities of the operators at the Flint plant. The OSD's, contained in Appendix E reflect all of the normal operations of the plant which primarily consist of inspections, recording data, and the taking of samples. While several nonroutine activities are included, there remain some emergency or other nonroutine actions which were not observed or recorded due to the seasonal nature of the action or due to the time limit of the on-site recording. It was found that the recording forms and inspection check-off lists that had been developed by the Flint plant were quite comprehensive and effective in standardizing the normal activities of the operators. However, in observing or recording by interview the procedures for routine control and nonroutine operations, such as restoring the plant to normal operations after a momentary power failure, it was found that each operator had his own ideas as to the procedures to be followed. Thus, standard operating procedures for routine control and nonroutine operations, with a few exceptions, do not exist at the Flint plant.

This is not unexpected even through Flint is considered a well-operated plant; most sewage plants do not have standard operating procedures which are geared to the operator. At best, some have operating manuals that are directed at how the equipment is to be operated. A major problem at Flint is operator turnover, particularly at the sub-foreman level. If written standard operating procedures for routine and nonroutine situations were available, training of new personnel would be greatly facilitated. The preparation of such routines by plant management would force a review of current practices and would provide an opportunity for evaluation and improvement.

Similarly, the Operational Staging Diagrams, the System/Equipment Staging Diagrams, the Function-Capability-Equipment Matrix, and the Process Flow Schematic are excellent visual training aids. These four industrial engineering techniques visually display the function of each unit in the plant, the equipment which accomplishes the function, and the standards or required capability expected of each unit, thus establishing a yardstick to evaluate the effectiveness of the unit and also how each unit fits into the overall plant process. The Equipment Staging Diagrams establish an indexing system upon which an effective operation cost accounting system can be based. That is, operation costs codified by the index number of the equipment staging document would facilitate evaluation of the costs by specific operational units or categories.

Flexibility

In addition to the findings discussed under Process Planning, the use of the Reliability Model as an industrial engineering technique to determine redundancy of equipment or facility requirements can be most effective during the concept design phase. As indicated previously, a discussion of the Reliability Model and the findings relative to its use as an industrial engineering technique to determine flexibility requirements are contained in Section IX.

RECOMMENDATIONS

From the results of the case study findings at Flint as well as consideration of current general practices, the following recommendations are offered in regard to operational aspects of conventional secondary treatment plants:

Flint Plant

Standard Operating Procedures (SOP's). To complement the check-off and recording forms which are used to standardize the inspection and sampling routine operations, it is recommended that the Flint plant develop SOP's for all nonroutine, emergency, and routine operations not covered by the check-off forms. These SOP's should be prepared as shown in Figure 7 using the OSD techniques as demonstrated in Appendix E.

PROCEDURE - ADJUSTMENT OF RETURN SLUDGE TO AERATION TANKS

NORMAL RESPONSIBILITY - Foreman or Senior Operator

REQUIREMENT - Adjustments in the amount of return sludge to the aeration tanks is necessary whenever the flow rate of the primary effluent to the aeration tanks varies significantly.

STANDARD OPERATING PROCEDURE

1 Pumping station reports change in flow rate of raw sewage.

OR

2 Operator checks "Raw Sewage Flow Printer" ("A-1," Sheet 3) on Console "A" in Meter Room and observes change in flow rate

3 Refer to "Foreman's log" to obtain current requirement for "% Return" of activated sludge flow.

4 Refer to "Return Activated Sludge Flow Conversion Table" (Sheet 5) Enter left side of table at top with "% Return" value and left column with "Raw Sewage Flow Printer" reading; obtain "Return Flow in MGD" number.

> Example of Step 4:
>
> For a "Raw Sewage Flow Printer" reading of 29 (obtained from Step 2) and with a current requirement of "% Return" of 35 (obtained from Step 3), a "Return Flow in MGD" number of 10.2 would be obtained from the table.

5 Enter right side of table at top with "Return Flow in MGD" number and obtain the "Meter Setting" number.

> Example of Step 5:
>
> For a "Return Flow in MGD" number of 10.2 (obtained from Step 4) a "Meter Setting" number of 3.4 would be obtained from the table.

Figure 7
Sample Standard Operating Procedure

Sheet 1 of 5

⑥ Adjust the round knobs on "Return Sludge to Aeration & Nit. Tank Ratio" controls (B-3, C-3, D-3, B-4, and D-4, Sheet 4) on console "B" to obtain the "Meter Setting" number (obtained from Step 5) on the "Return Sludge to Aeration & Nit. Tank" meter (B-1, C-1, D-1, B-2, C-2, D-2, Sheet 4) for each tank designated to receive return sludge.

Example of Step 6:

Tanks 1, 3, 5, and 9 are designated to receive return sludge. Before adjustment, meters B-1, C-1, D-1, and B-2 each read approximately 9.5.

Turn the round knobs clockwise on controls B-3, C-3, D-3, and B-4 until each meter reads 10.2.

Figure 7
Sample Standard Operating Procedure
(Continued)

Sheet 2 of 5

METER & CONTROL CONSOLE "A"

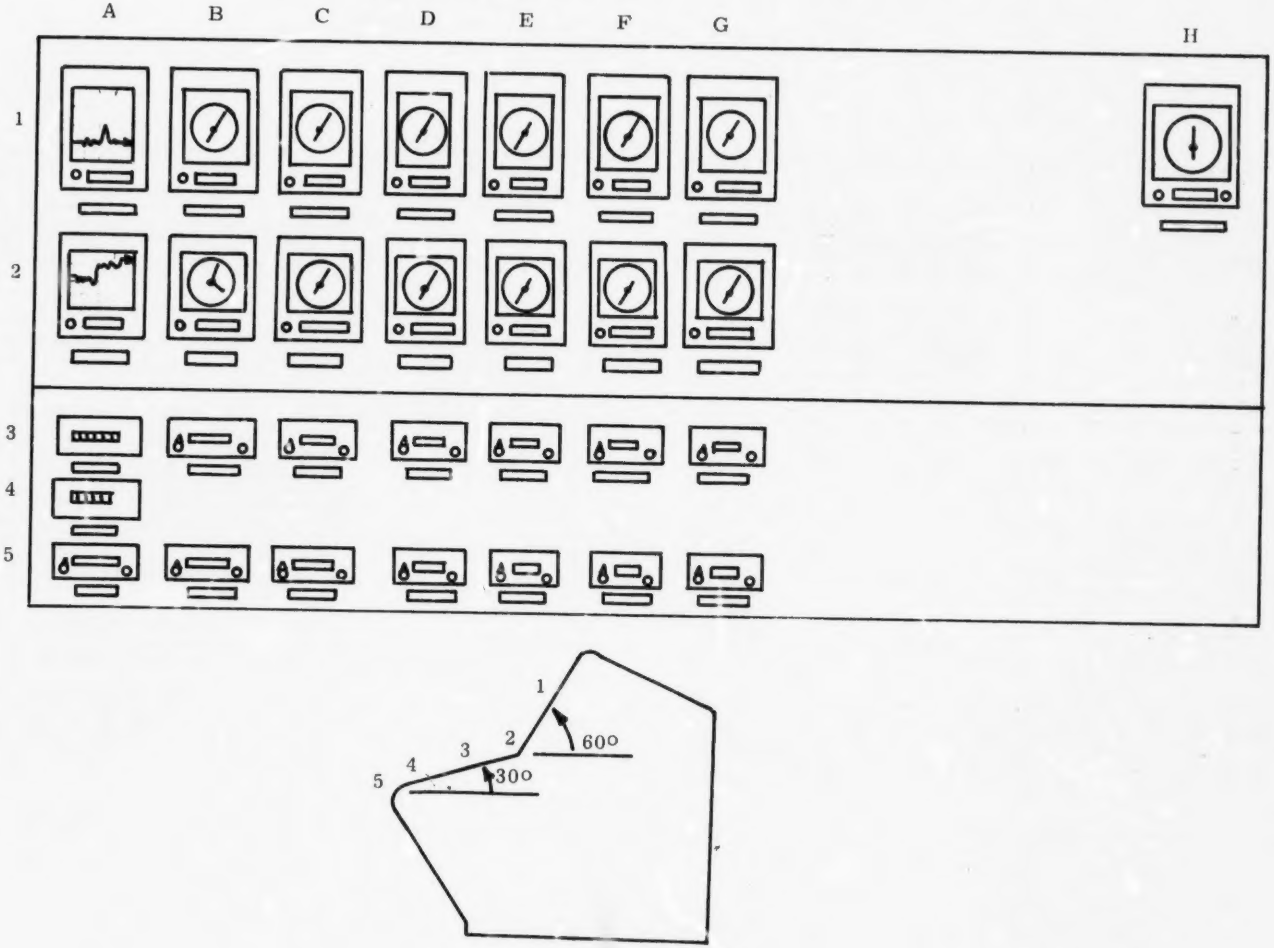

A
B
C
D
E
F
G
H
1
2
3
4
5
1
2
3
4
5
60°
30°

Figure 7
Sample Standard Operating Procedure
Return Activated Sludge Flow Conversion Table
(Continued)

Sheet 3 of 5

METER & CONTROL CONSOLE "B"

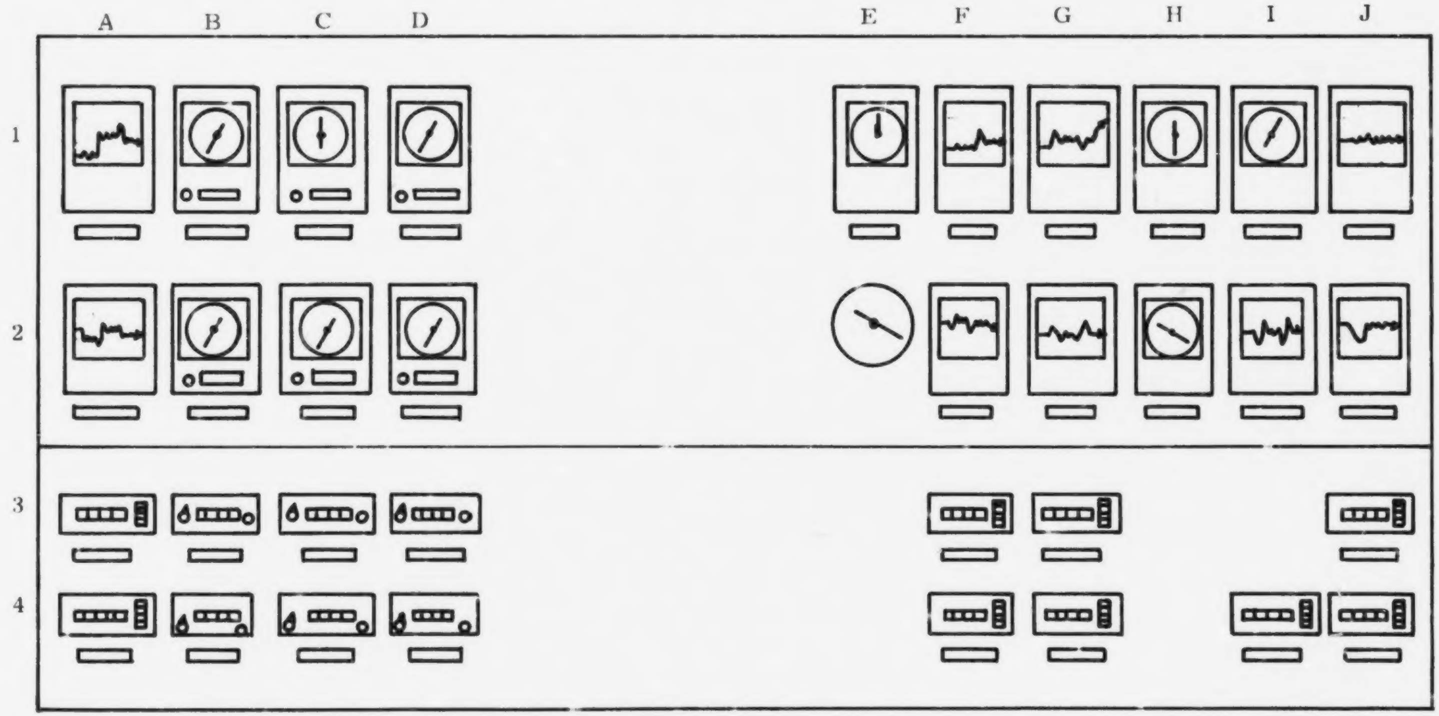

A
B
C
D
E
F
G
H
I
J
1
2
3
4

Figure 7
Sample Standard Operating Procedure
Return Activated Sludge Flow Conversion Table
(Continued)

Sheet 4 of 5

Flow	% RETURN					Return Flow In MGD	Meter Seting	Return Flow In MGD	Meter Seting
	25	30	35	40	45				
14	3.5	4.2	4.9	5.6	6.3	3.5	1.2	9.1-9.5	3.1
16	4.0	4.8	5.6	6.4	7.2	4.0	1.3	9.6-9.8	3.2
18	4.5	5.4	6.3	7.2	8.1	4.2	1.4	9.9-10.0	3.3
20	5.0	6.0	7.0	8.0	9.0	4.5	1.5	10.2	3.4
21	5.3	6.3	7.4	8.4	9.5	4.8-4.9	1.6	10.4-10-5	3.5
22	5.5	6.6	7.7	8.8	9.0	5.0	1.7	10.8-10.9	3.6
23	5.8	6.9	8.1	9.2	10.4	5.3.5.5	1.8	11.2-11.3	3.7
24	6.0	7.2	8.4	9.6	10.8	5.6-5.8	1.9	11.6-11.7	3.9
25	6.3	7.5	8.8	10.0	11.3	6.0	2.0	11.9-12.2	4.0
26	6.5	7.8	9.1	10.4	11.7	6.3-6.4	2.1	12.3-12.4	4.1
27	6.8	8.1	8.5	10.8	12.2	6.5-6.6	2.2	12.6	4.2
28	7.0	8.4	9.8	11.2	12.6	6.8-7.0	2.3	12.8	4.3
29	7.3	8.7	10.2	11.6	13.1	7.2-7.3	2.4	13.1-13.2	4.4
30	7.5	9.0	10.5	12.0	13.5	7.4-7.5	2.5	13.5-13.6	4.5
31	7.8	9.3	10.9	12.4	14.0	7.7-7.8	2.6	14.0	4.7
32	8.0	9.6	11.2	12.8	14.4	8.0-8.1	2.7	14.4	4.8
33	8.3	9.9	12.6	13.2	14.9	8.3-8.5	2.8	14.9	5.0
34	8.5	10.2	11.9	13.6	15.3	8.7-8.8	2.9	15.3	5.1
35	8.8	10.5	12.3	14.0	15.8	9.0-9.1	3.0	15.8	5.3

Figure 7
Sample Standard Operating Procedure
Return Activated Sludge Flow Conversion Table
(Continued)

Sheet 5 of 5

Operation Cost Accounting System. To establish a management system for evaluating operating costs, it is recommended that the Flint plant codify operational and maintenance costs with the index numbering system of the System/Equipment Staging Diagram contained in Appendix D. This will provide ready identification of cost factors leading to better cost control.

Training Aids. It is recommended that the Flint plant use the Functional Staging Diagrams, Appendix B; the Plant Layout Diagram, Appendix C; the Equipment Staging Diagrams, Appendix D; the Operational Sequencing Diagrams, Appendix E; and the SOP's developed in response to the above recommendation as visual aids in the training of regular operators and operator-trainees. These can be collected in a manual form as a reference source for the trainee or can be incorporated in an in-service training program. These documents not only fully describe the logic and procedures which govern plant operations but also are the basis for ongoing plant management.

GENERAL

Design Procedure

Because of the benefits derived from the rational organization of data, it is recommended that the following techniques be considered for general use in developing designs and specifications of waste treatment plants:

Technique	Use
Functional Staging	Methodical analysis of objective of system; checklist
System/Equipment Staging	Promote equipment checklist; index basis
Function-Capability-Equipment Matrix	Promote rational design based on capability requirements; checklist for design data
Correlation Matrix and Adjacency Chart	Optimize physical layout and equipment management
Reliability Model	Identification of requirements for redundant elements (See Section IX)

Establish Standard Operating Procedures (SOP's)

In order to optimize efficiency of routine type operations, SOP's should be required as part of the operating manuals for new or existing plants. The OSD technique, as shown in Figure 7 and Appendix E, is recommended as a basic technique for Standard Operating Procedure development. Using the OSD's and the SOP's, recording forms and inspection check-off lists can be developed to provide guidance to the operating and maintenance personnel and assure that the SOP's are followed.

Operation Cost Accounting System

It is recommended that wastewater treatment plants develop System/Equipment Staging Diagrams, similar to Appendix D, not only for design use as discussed throughout this section, but for use in codifying operational and maintenance costs. The codifying system should be based on the index numbering system of the System/Equipment Staging Diagram.

Training Aids

In establishing training programs for new plants or revising existing training programs, it is recommended that Functional Staging Diagrams similar to Appendix A, Process Flow Schematics similar to Appendix B, Plant Layout Diagrams similar to Appendix C, Equipment Staging Diagrams similar to Appendix D, Operational Sequencing Diagrams similar to Appendix E, and Standard Operating Procedures prepared as shown in Figure 7 be developed and used as training aids.

Development of a Function-Capability-Equipment Matrix for General Application

It is recommended that the concept of the Function-Capability-Equipment Matrix technique as shown in Figure 6 be extended to develop a matrix wherein the design parameters or characteristic elements which define the capabilities required to perform a specific function are set forth. The matrix would cover all functions and subfunctions in the Functional Staging Diagram for all commonly employed unit operations or subsystems. Design parameters are characteristic elements which are fixed by standards or by design criteria would be set forth in quantitative or definitive terms. Where the design parameters or characteristic elements which have variable quantities or which cannot be specifically stated due to the requirements of the individual design, they could be set forth so that the design engineer would only have to fill in the data in an appropriate blank. The development of such a matrix for all the commonly used unit operations or subsystems would give the design engineer a tool which would facilitate his conceptual design task to ensure coverage of all required capabilities of the total system. Types of equipment required to perform the function would be listed. However, the quantity and size of equipment would be left blank, thus permitting the design engineer to fill in the information based on his evaluation of the determined capabilities for the specific function. In addition, provisions would be made to include alternative equipment if desired. In essence, the matrix could be a wastewater treatment system design check-off list.

SECTION VI

EVALUATION OF WORK STUDY TECHNIQUES ON MAINTENANCE ACTIVITIES

No manufacturing facility, no matter how well designed, will be capable of acceptable performance over an extended period unless it is properly maintained. This is particularly true of waste treatment plants because of the characteristics of sewage. Most sewage treatment plants are underfunded to meet general operating expenses. Operational and quality assurance functions are normally given higher priority since the result of their neglect is almost immediate: poor performance or insufficient data for the regulatory agency. Expenditures for preventive maintenance, however, are relatively long term investments similar in certain respects to insurance policies; one pays to avoid an undesirable future event. The amount one is willing to pay depends upon the payer's assessment of the probability of the event's occurrence and the penalties associated with the event. Success in this case is not dramatic - the plant performs as desired. Given the current policies in regard to funding and priorities, it is not surprising to find that most plants have poor maintenance management programs.

The following subsections include a discussion of criteria for successful maintenance programs both in the context of industrial engineering and as they relate to waste treatment. This will be followed by a description of the industrial engineering approaches applied in the case study along with general results and conclusions.

CRITERIA

Maintenance Planning and Procedures

Above all else, proper or optional maintenance is dependent upon an effective maintenance management program. Preventive maintenance, if it is to be effective, must be planned and controlled and the procedures involved must be clearly defined. The objectives of a maintenance management program include the development of a system which will:

Define the minimum requirements of planned maintenance

Reduce the maintenance of equipment to simple procedures easily identified and managed

Schedule and control the performance of work tasks, inspections, and tests

Describe the methods, materials, tools, and personnel required

Provide for the prevention or detection of impending malfunctions

Develop and evaluate maintenance cost information

In accomplishing these objectives the maintenance management system should contain certain basic elements:

Equipment Records. Each piece of equipment must be described in detail, listing all information required to locate and identify the unit and its major components. The information contained in the Equipment Record Files provides a central source of information pertinent to the several major aspects of equipment preventive maintenance. It provides a means of rapidly reviewing the history of each piece of equipment, including the past maintenance and repairs, reported maintenance cost requirements, and a summary of maintenance costs.

Preventive Maintenance System (PM). The objective of a sound maintenance management program is to obtain maximum economy and efficiency in the operation of equipment. An adequate PM system will maintain equipment in a satisfactory condition by providing for the systematic inspection, detection, and correction of incipient failures, either before they occur or before they develop into major defects. The particular check points on the equipment, the frequency of attention, and the schedule of performing the PM and follow-up repair work should all be determined in advance of actual performance of the work. The work should be measured by time standards and control procedures should be built into the system that will indicate the effectiveness of the PM program and to make adjustments to improve its effectiveness.

Work Order System. In order to control maintenance work, it is necessary to have some type of work order system. Such a system when established should determine the size of the approved work load, what type of work is necessary, and what that work is costing. A well designed Work Order System is the core to effective maintenance operation. It goes beyond being merely a means to transmit information. It is the tool by which sound work load planning and scheduling is accomplished.

Planning and Scheduling Maintenance Work. A system should be established which provides for both short-range and long-range planning and scheduling to the proper maintenance groups. Long-range planning and scheduling consist of establishing the preventive maintenance routines and planned overhauls. Short-range scheduling includes the assigning of jobs to maintenance workers on a day-to-day or week-to-week basis. The short-range planning coordinates the scheduling so that there will be a minimal conflict with the normal operation of the equipment.

Preventive Maintenance Ratio. One criterion that has been advanced for utility systems is that manpower resources expended in preventive maintenance should be at least 50 percent of the combined total manpower resources spent for both repair (corrective) and Preventive Maintenance. However, experience has shown that it is not practical to base one plant's amount of PM on the amount at some other plant. The ratios published periodically can only be a guide. Each plant must find its own best level. Control reports should be established to permit this to be done with simplicity and confidence.

Maintenance Reporting. An effective maintenance management program includes the provisions for reporting: (1) maintenance action accomplished for equipment history recording purposes as both a check for management and as a performance record for the equipment; (2) material and spare parts expenditures for restocking purposes and recording of costs; and (3) man-hour expenditures for recording labor costs and for comparison of actual times with time standards for the purpose of revising existing maintenance schedules or establishing new schedules. Costing data is essential for establishing budgets. The reporting system should be simple and easily accomplished by the maintenance technicians with limited assistance from clerical type personnel.

Material Support

The important elements for obtaining an effective maintenance stores control system are:

Spare Parts Inventory. The number and type of spare parts stocked should be based on historical records of consumption and usage. Materials or spare parts which may be difficult to obtain promptly from suppliers or used in equipment for which prolonged downtime is considered costly or unsafe should be considered as high priority on the inventory list. Materials and replacement parts required for scheduled maintenance should be anticipated and procured in sufficient time so as to not delay work.

Inventory Control. Adequate records should be maintained to control issuance of tools and materials and to control the replenishment of these materials. Material should be maintained in usable condition and easy to locate when needed. The latter is best accomplished by a classification system which is based on a code number keyed to the material type or in the case of spare parts, to the specific item of equipment. Costing data should also be documented to facilitate the reporting of maintenance costs to management.

APPLIED INDUSTRIAL ENGINEERING TECHNIQUES

Several industrial engineering techniques that were applied in the recording, development, and evaluation of data at the Flint plant were related to maintenance activities; these are discussed below.

Functional Staging

Functional Staging Diagrams (FSD's), Appendix A, were developed to visually display the functions and subfunctions which a utility plant maintenance group is required to perform. Functions and subfunctions down to the fourth level are shown in the FSD's. Subfunctions below the fourth level for preventive maintenance only were developed as part of the effort to determine staffing requirements and are included in the Operational/Maintenance Task Matrices, Appendix F. These matrices are discussed in Section VII.

System/Equipment Staging Diagrams

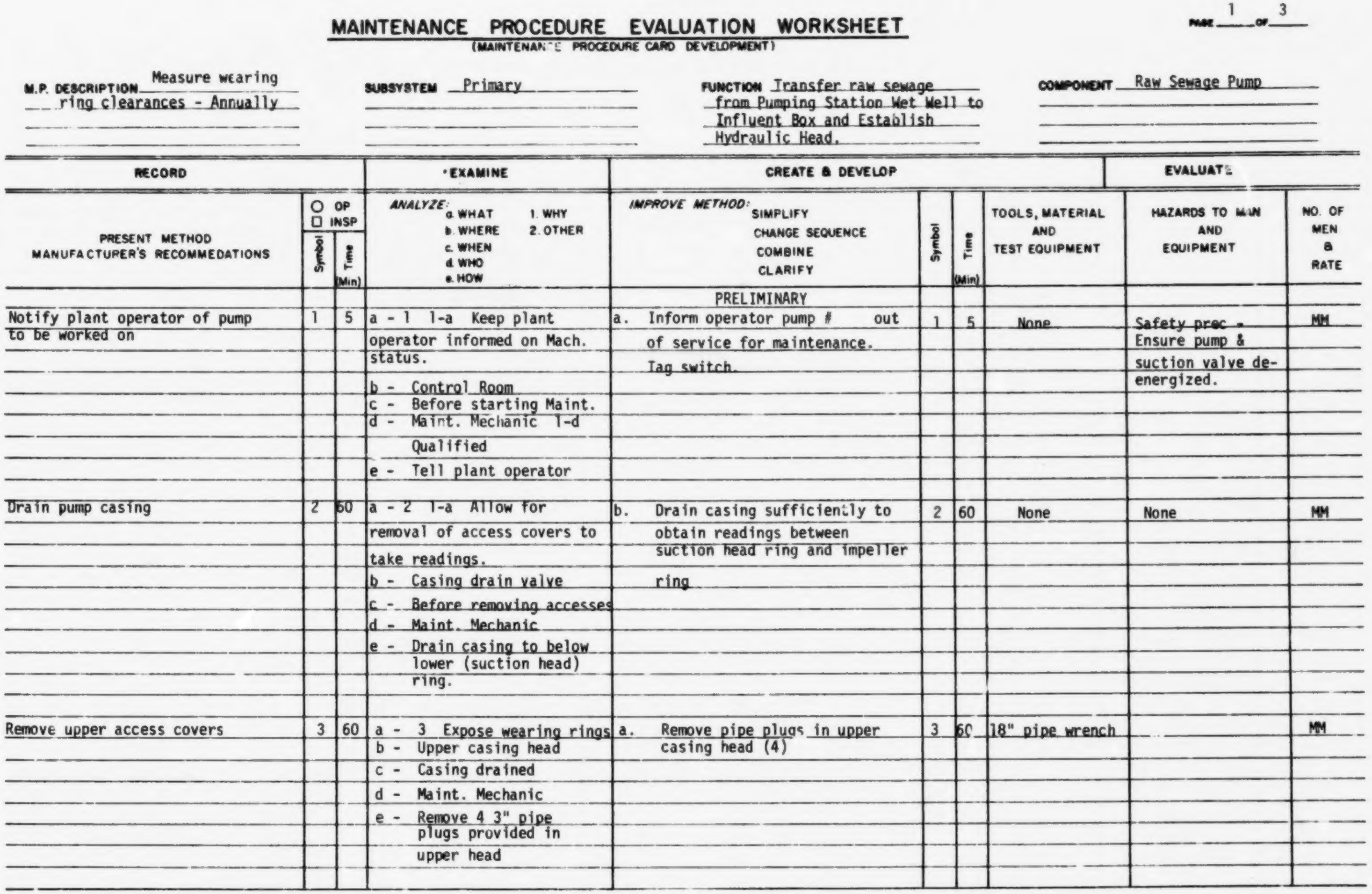
The System/Equipment Staging Diagrams, Appendix D, and the equipment inventory for the Flint plant developed therefrom, which were discussed in Section V, were developed and used as a check-off list to determine which equipment was required to be included in the Preventive Maintenance Program.

Maintenance Procedure Evaluation (MPE) Worksheet

To demonstrate an industrial engineering technique for developing preventive maintenance requirements for specific equipment, a Maintenance Procedure Evaluation (MPE) Worksheet Figure 8, was prepared. This worksheet is basically a Critical Examination Analysis worksheet and, as such, methodically records the WHAT, WHEN, WHO, and HOW of a required maintenance action. It includes the evaluation of data gathered from such documents as manufacturers' technical manuals, maintenance handbooks, standard timetables, and related reliability data. The MPE worksheet was used to develop the Maintenance Procedure Card (MPC) which is shown in Figure 9 for a raw sewage pump.

Operational Sequence Diagram (OSD)

The flow process of a requisition for a spare part was documented by the OSD technique from the inception of the requirement for the spare part to the receipt of the part and the preparation of the payment document. This document, shown in Appendix E, was prepared to indicate how management functions could be effectively displayed for convenient evaluation.



PAGE 1 OF 3

MAINTENANCE PROCEDURE EVALUATION WORKSHEET

(MAINTENANCE PROCEDURE CARD DEVELOPMENT)

M.P. DESCRIPTION Measure wearing ring clearances - Annually

SUBSYSTEM Primary

FUNCTION Transfer raw sewage from Pumping Station Wet Well to Influent Box and Establish Hydraulic Head.

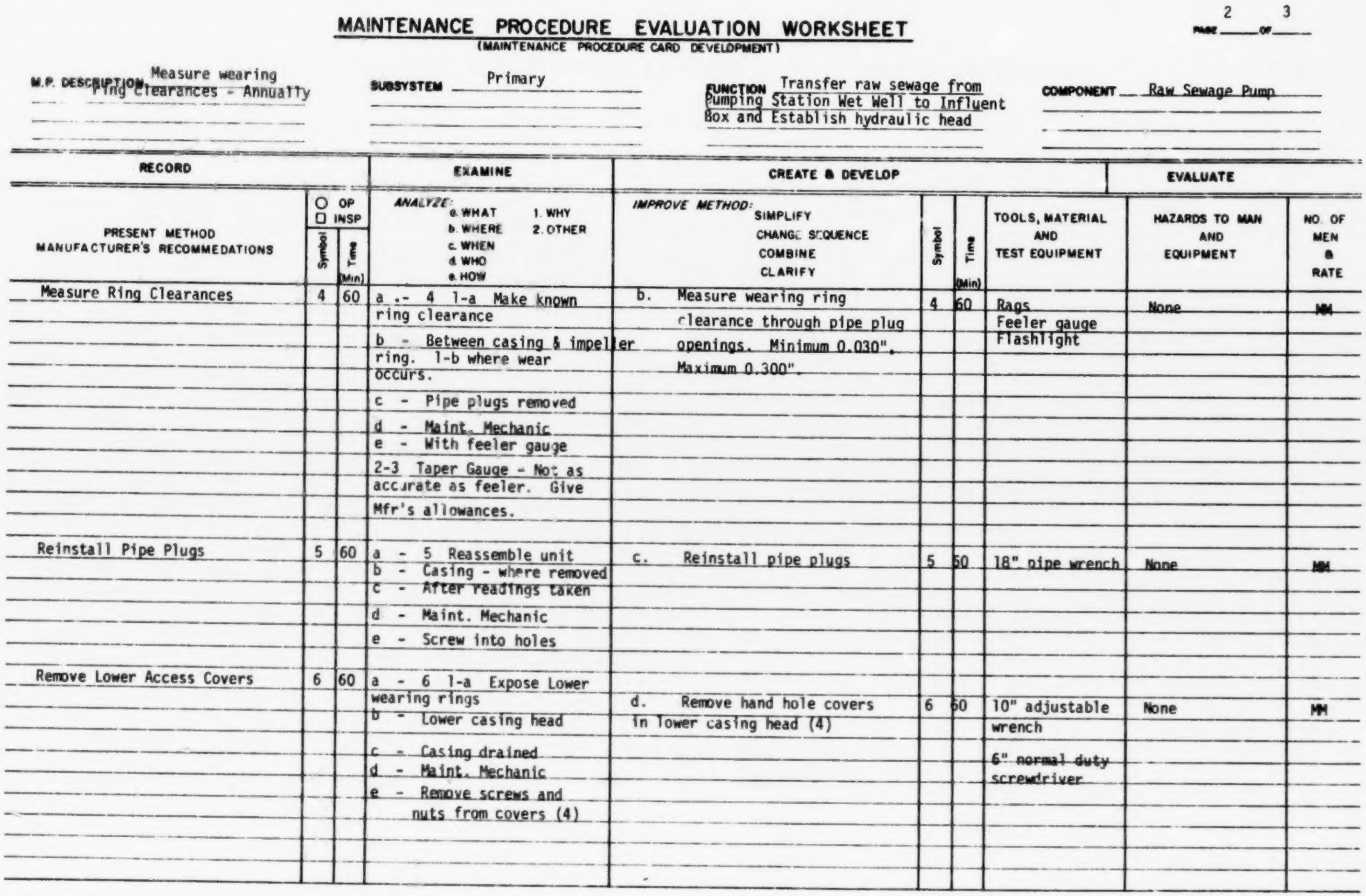
COMPONENT Raw Sewage Pump

RECORD			*EXAMINE	CREATE & DEVELOP				EVALUATE	
PRESENT METHOD MANUFACTURER'S RECOMMEDATIONS	○ OP ☐ INSP Symbol	Time (Min)	ANALYZE: a. WHAT b. WHERE c. WHEN d. WHO e. HOW 1. WHY 2. OTHER	IMPROVE METHOD: SIMPLIFY CHANGE SEQUENCE COMBINE CLARIFY	Symbol	Time (Min)	TOOLS, MATERIAL AND TEST EQUIPMENT	HAZARDS TO MAN AND EQUIPMENT	NO. OF MEN & RATE
				PRELIMINARY					
Notify plant operator of pump to be worked on	1	5	a - 1 1-a Keep plant operator informed on Mach. status.	a. Inform operator pump # out of service for maintenance.	1	5	None	Safety prec - Ensure pump &	MM
				Tag switch.				suction valve de-energized.	
			b - Control Room						
			c - Before starting Maint.						
			d - Maint. Mechanic 1-d Qualified						
			e - Tell plant operator						
Drain pump casing	2	60	a - 2 1-a Allow for removal of access covers to take readings.	b. Drain casing sufficiently to obtain readings between suction head ring and impeller ring	2	60	None	None	MM
			b - Casing drain valve						
			c - Before removing accesses						
			d - Maint. Mechanic						
			e - Drain casing to below lower (suction head) ring.						
Remove upper access covers	3	60	a - 3 Expose wearing rings	a. Remove pipe plugs in upper casing head (4)	3	60	18" pipe wrench		MM
			b - Upper casing head						
			c - Casing drained						
			d - Maint. Mechanic						
			e - Remove 4 3" pipe plugs provided in upper head						

Figure 8

Sample Maintenance Procedure Evaluation Worksheet

Sheet 1 of 3



MAINTENANCE PROCEDURE EVALUATION WORKSHEET

(MAINTENANCE PROCEDURE CARD DEVELOPMENT)

PAGE 2 OF 3

M.P. DESCRIPTION Measure wearing ring Clearances - Annually

SUBSYSTEM Primary

FUNCTION Transfer raw sewage from Pumping Station Wet Well to Influent Box and Establish hydraulic head

COMPONENT Raw Sewage Pump

RECORD			EXAMINE	CREATE & DEVELOP				EVALUATE	
PRESENT METHOD MANUFACTURER'S RECOMMEDATIONS	○ OP ☐ INSP Symbol	Time (Min)	ANALYZE: a. WHAT b. WHERE c. WHEN d. WHO e. HOW 1. WHY 2. OTHER	IMPROVE METHOD: SIMPLIFY CHANGE SEQUENCE COMBINE CLARIFY	Symbol	Time (Min)	TOOLS, MATERIAL AND TEST EQUIPMENT	HAZARDS TO MAN AND EQUIPMENT	NO. OF MEN & RATE
Measure Ring Clearances	4	60	a .- 4 1-a Make known ring clearance b - Between casing & impeller ring. 1-b where wear occurs. c - Pipe plugs removed d - Maint. Mechanic e - With feeler gauge 2-3 Taper Gauge - Not as accurate as feeler. Give Mfr's allowances.	b. Measure wearing ring clearance through pipe plug openings. Minimum 0.030". Maximum 0.300".	4	60	Rags Feeler gauge Flashlight	None	MM
Reinstall Pipe Plugs	5	60	a - 5 Reassemble unit b - Casing - where removed c - After readings taken d - Maint. Mechanic e - Screw into holes	c. Reinstall pipe plugs	5	60	18" pipe wrench	None	MM
Remove Lower Access Covers	6	60	a - 6 1-a Expose Lower wearing rings b - Lower casing head c - Casing drained d - Maint. Mechanic e - Remove screws and nuts from covers (4)	d. Remove hand hole covers in lower casing head (4)	6	60	10" adjustable wrench 6" normal duty screwdriver	None	MM

Figure 8

Sample Maintenance Procedure Evaluation Worksheet (Continued)

Sheet 2 of 3

MAINTENANCE PROCEDURE EVALUATION WORKSHEET

(MAINTENANCE PROCEDURE CARD DEVELOPMENT)

PAGE 3 OF 3

M.P. DESCRIPTION Measure wearing ring clearances - Annually

SUBSYSTEM Primary

FUNCTION Transfer raw sewage from Pumping Station Wet Well to Influent Box and Establish Hydraulic Head.

COMPONENT Raw Sewage Pump

RECORD			EXAMINE	CREATE & DEVELOP				EVALUATE	
PRESENT METHOD MANUFACTURER'S RECOMMEDATIONS	○ OP ☐ INSP Symbol	Time (Min)	ANALYZE: a. WHAT b. WHERE c. WHEN d. WHO e. HOW 1. WHY 2. OTHER	IMPROVE METHOD: SIMPLIFY CHANGE SEQUENCE COMBINE CLARIFY	Symbol	Time (Min)	TOOLS, MATERIAL AND TEST EQUIPMENT	HAZARDS TO MAN AND EQUIPMENT	NO. OF MEN & RATE
Measure wearing ring clearance	7	60	a - 7 1-a Make known clearance	e - Measure wearing ring clearance through hand hole openings Minimum 0.030", maximum 0.300".	7	60	Feeler gauge Rags Flashlight	None	MM
			b - Between casing and impeller ring 1-b where wear occurs						
			c - Covers removed. Rings accessible thru openings						
			d - Maint. Mechanic						
			e - Feeler gauge 1-c Get accurate readings. Give Mfr. allowances						
Reinstall covers	8	60	a - 8 1-a Reassemble unit	f - Reinstall hand hole covers	8	60	10" adjustable wrench 6" normal duty screwdriver	None	MM
			b - Lower casing head						
			c - Readings taken						
			d - Maint. Mechanic						
			e - Reinstall with screws & nuts						
Notify Operator when finished	9	5	a - 9 1-a Keep plant operator informed of Mach. status.	g - Notify operator maintenance complete. Remove warning tag.	9	5	None	None	MM
Note: When Max. Clearance of .300" is reached, notify Maint. Supvr. Wear rate indicates that pump will reach max. wear limit of .312" and require replacement of wearing rings in approx. 6 to 8 months hence.			b - Control Room						
			c - Maint. complete						
			d - Maint. Mechanic	Subtotal		430			
			e - Tell plant operator	10% Factor		43			
				Total		473	= 8.0 m/h		

Figure 8

Sample Maintenance Procedure Evaluation Worksheet (Continued)

Sheet 3 of 3

SUBSYSTEM Primary	**COMPONENT** Pump	**SYSTEM INDEX NO.** 11100/03 **FREQ.** A-3
EQUIPMENT Sewage Pump & Motor	**MANUFACTURER** Chicago Pump	**MAINTENANCE PERSONNEL** Maint.Mech. **M/H** 8.0
LOCATION Northwest Pumping Station - Pump Level	**RELATED MAINTENANCE** None	**TOTAL M/H** 8.0 **ELAPSED TIME** 8.0

SAFETY PRECAUTIONS

1. Observe standard safety precautions.
2. Ensure pump controller and suction valve have been de-energized. Tag switch.

MAINTENANCE REQUIREMENT DESCRIPTION

1. Measure wearing ring clearances.

TOOLS, PARTS, MATERIALS, TEST EQUIPMENT

1. Rags
2. Flashlight
3. Feeler gauge
4. 18" Pipe wrench
5. 10" Adjustable wrench
6. 6" Normal duty screwdriver

PROCEDURE

Page 1 OF 1

MPC NO 49-082

Preliminary

a. Inform operator pump #____ out of service for maintenance.
b. Drain pump sufficiently to obtain readings between suction head ring and impeller ring.

Measure Wearing Ring Clearances.

a. Remove pipe plugs in upper casing head (4).
b. Measure wearing ring clearance through pipe plug openings. Minimum .030", maximum .300".
c. Reinstall pipe plugs.
d. Remove hand hole covers in lower casing head (4).
e. Measure wearing ring clearance through hand hole openings. Minimum .030", maximum .300".
f. Reinstall hand hole covers.
g. Remove warning tag and notify operator maintenance complete.

NOTE: When maximum clearance of 0.300" is reached, notify maintenance supervisor. Wear rate indicates that pump will reach maximum wear limit of 0.312" and require replacement of wearing rings in approximately 6 to 8 months hence.

MAINTENANCE PROCEDURE CARD (MPC)

Figure 9
Example of Maintenanc[illegible]rocedure Card

Standard-Time Tables

Time standards for accomplishing various maintenance and service tasks are contained in several industrial engineering handbooks. These standards are based on data gained by time and motion studies. The data are based on statistical sampling and are applicable to those maintenance functions that are commonly practiced (lubrication, replacing wiring, etc.). The reference use of these standards as an industrial engineering tool to develop maintenance procedures is generally highly advantageous.

FINDINGS

Maintenance Planning and Procedures

In developing a maintenance management program for a wastewater treatment plant, three industrial engineering techniques or tools can be applied:

System/Equipment Staging

Maintenance Procedure Evaluation (MPE) Worksheet

Standard-Time Tables

The logical steps in planning maintenance actions and developing maintenance procedures for specific plant equipment are: (1) develop System/Equipment Staging Diagram to establish an equipment inventory for the plant; (2) Analyze the preventive maintenance requirements for each piece of equipment using the Maintenance Procedure Evaluation (MPE) Worksheet, Figure 8, with standard times applied to the work covered; (3) prepare Maintenance Procedure Cards (MPC's), such as shown in Figure 9, for each preventive maintenance action (daily, weekly, etc.) for each component of the equipment requiring such maintenance action; and (4) develop master schedules based on the frequencies of maintenance action set forth in the individual MPC's. The MPC so developed sets forth the procedures in simple instructions, defines minimum requirements, and lists the time, materials, tools, and personnel skill requirements. The collective MPC's for a plant are the basis of the maintenance management program and also serve as an excellent training tool.

The Flint plant was found to have a simple but reasonably effective preventive maintenance program for the machinery group which consisted of mimeographed check-off lists delineating general areas of maintenance action for all equipment. The check-off lists were grouped by location and by frequency of action (weekly and monthly). Detailed instructions were not provided; therefore, the Maintenance Mechanic was required to interpret the general instructions to determine his own methods or procedures for accomplishing the task. The check-off lists are issued by a work-order system which is effective in assigning the work to the proper maintenance group and skill. The work-order system provides for recording of maintenance action taken for machinery history purposes.

purposes. However, the system does not provide for recording of man-hours or material cost data. Due to the magnitude of repair or corrective maintenance of instruments and electrical equipment and shortage of an electrician, the plant performs very little or no preventive maintenance on electrical equipment. The plant expends approximately 10 percent of manpower resources on scheduled preventive maintenance, 20 percent on nonscheduled preventive maintenance, and 70 percent on repair or corrective maintenance.

In summary, the Flint plant has a partially successful maintenance program. What is lacking is an overall management program to document and standardize actions and to evaluate the costs and effectiveness of the program.

Material Support

The index system of the System/Equipment Staging Diagram, Appendix D, provides a classification system for grouping spare parts. Spare parts would then be keyed to the specific item of equipment, thereby facilitating the recording of cost data by systems or subsystems. If the maintenance records are also keyed to the System/Equipment Staging index system, the developing of usage data for spare parts would be facilitated.

The Flint plant has an informal inventory control system which does not facilitate recording of spare parts usage or cost data.

RECOMMENDATIONS

From the results of the case study at the Flint plant as well as consideration of current general practices, the following recommendations are offered in regard to maintenance management programs for conventional secondary plants.

Flint Plant

Maintenance Control Indexing System. It is recommended that the Flint plant adopt an indexing system for all equipment based on the System/Equipment Staging Diagram, Appendix D. This will provide a standard framework for a system for data collection, recording, and retrieval on equipment maintenance requirements, actions, and costs.

Maintenance Procedure Cards. In order to ensure uniformity in maintenance actions and to clearly identify maintenance requirements, the preparation of maintenance procedure cards is recommended. This will not only avoid variations in the quality of maintenance but will also be a valuable training aid.

Additional Maintenance Personnel. As stated earlier, a rule of thumb for a maintenance program for utility systems that is under control is to have at least 50 percent of the maintenance effort put into preventive maintenance. Although this is only a guide, it is a known fact that more PM than is needed at the beginning is less costly in the end. Less PM than is needed almost always results in more emergency or corrective maintenance which cannot be scheduled and is inefficient from a manpower application point of view. At Flint, only about 30 percent of maintenance is PM. It is recommended that an additional maintenance specialist, an electrician, be hired to perform the electrical PM which is now inadequately handled.

General

Maintenance Program Development. In establishing a preventive maintenance program for new plants or revising procedures at existing plants, it is recommended that a comprehensive maintenance management program be developed using the following techniques:

Use the System/Equipment Staging Diagrams to establish an equipment inventory list that is conveniently indexed

Identify maintenance requirements for each piece of equipment using an extension of the function capability/equipment list

Analyze PM requirements for each component using the Maintenance Procedure Evaluation Worksheet

Prepare Maintenance Procedure cards

Develop Master Maintenance Schedule

Detailed descriptions of procedures for the development of maintenance management programs should be presented in a manual for general use by wastewater plant managers.

SECTION VII

APPLICATION OF WORK STUDY TECHNIQUES TO STAFFING OF WASTEWATER TREATMENT PLANTS

DISCUSSION

Successful production of any product, including treated sewage, is dependent upon the effective application of men and equipment suitable for performing the required tasks. Staffing of a plant includes the number of people required as well as their skill level. The application of the staff has previously been discussed in terms of operations and maintenance functions. This section will deal with techniques used to develop staffing levels.

Currently, staffing at waste treatment plants is determined on an empirical basis. Some of the larger consulting firms maintain data from past experience from which they base their recommendations. Currently, an EPA sponsored project is attempting to collect staffing data from a large number of plants of various designs and capabilities. The expected results are a series of correlations between plant size and staffing. Using this information, a designer could estimate required staff by use of a series of charts derived from a large number of existing plants. The estimate must be modified by the particular conditions and design of the plant under consideration. In most cases, however, staff size determination for new plants is based upon minimal analysis of requirements and can be considered as an educated guess. This is modified for new or expanded plants by the willingness of the governmental unit (city, county, etc.) to provide operating funds. In those cases where the regulatory agency has not set stringent effluent quality requirements, there is little incentive for the plant to be adequately staffed. Thus, treatment plant management can be faced with the need to request additional operating funds for staff from an already tight municipal budget without having strong backup justification in the form of accepted staffing standards or strong regulatory pressure.

The usual procedure that would be used by industrial engineers for determining the value of an individual job with other jobs in an organization is job evaluation. The salient features of the procedure are that it:

Starts with job analysis

Obtains relative rather than absolute values of jobs

Groups the jobs into classes for which minimum and maximum wages are established

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Of the three characteristics above, job analysis is probably the most important because it is the foundation for the whole job evaluation structure. It is the procedure that would be used to develop personnel requirements for a job. A job is defined as a combination of tasks. A job normally consists of (1) preparation, (2) travel, (3) task performance, (4) cleanup, and (5) allowances. (The latter covers such factors as personal needs, fatigue, unavoidable delays, and the effect of the environment.) Job analysis involves a careful study of each job to find out just what the job includes, what the job-holder does, how he does it, under what conditions the job is performed, how the job relates to other jobs, and what special qualifications the job-holder must have. It is an intensive, direct method of obtaining the pertinent facts about jobs. It includes the observation of the job and the reporting of facts which are observed and which are obtained in conversation with workers, supervisors, and others who have information of value.

In analyzing an operation to determine effectiveness, three factors are involved which management can use as a productivity index:

Utilization	the degree to which resources are productively occupied
x	
Methods	the way in which resources are used
x	
Performance	the level of skill and effort expended while productively occupied
=	
Productivity Index	

An estimate of potential benefits can be shown by an example. The present level of productivity is established by estimating a percentage value for each factor and multiplying them. Assume that in a given maintenance group, the workers are utilized productively for 70 percent of available hours, that the methods level used while working is 80 percent, and that the workers have an average performance level of 95 percent. The productivity index for the group is:

70% x 80% x 95% = approximately 53%

To continue the example, suppose there are ten men working in this department. With a productivity level of 54 percent, the same work could, theoretically, be produced by six men (54 percent of 10 men). This could only be done if each productivity factor were raised to 100 percent. This is not unrealistic but would be quite difficult and costly to achieve. It is realistic, however, to raise the utilization level from 70 percent to 85 percent and to improve the methods level from 85 percent to 95 percent. With performance unchanged, the new productivity level is shown on the following page.

85% x 95% x 95% - approximately 77%

The difference in manning would be:

$$\frac{77\% - 53\%}{53\%} = \text{approximately } 42\%$$

or

42% x 10 men = 4 men

Productivity is, therefore, a result or the end product of management effectiveness. Methods are dependent upon the degree of attention management provides in determining how a work task is to be performed. In addition, management can exert a great influence on productivity by improving the utilization of the workers' time. To do this,it has only to concentrate on the application of improved work load planning and management controls.

Regular operations in a utility or service type plant are relatively minor in comparison to maintenance. One of the most important maintenance functions is that of inspections. In order to emphasize preventive maintenance and thereby minimize repair or corrective maintenance, only the most skilled and experienced men should be used for maintenance inspections since these people are most qualified to identify potential problems.

A major factor which influences employee performance is morale. In general there are four factors in which workers are interested: (1) security (including pay); (2) opportunity; (3) recognition; and (4) inclusion (awareness of being part of an operation). In order to satisfy these elements, particularly the second, plant management should have a "career ladder" or incentive program where employees qualify for higher positions within the plant organization or within a broader organization, such as a municipal public works department, on the basis of general ability and skills acquired through intensive training courses. Given basic intelligence and desire, "hard core unemployed" could be employed at the lower levels and by participation in such training programs progress to the higher levels.

APPLIED INDUSTRIAL ENGINEERING TECHNIQUES

Because of the nature of the preceding features, industrial engineering techniques, as such, are only applicable to certain aspects of staffing determinations. In other cases, current conditions in the waste treatment field are compared to practices in industry and are discussed in a later section.

Operational Sequence Diagrams (OSD's)

The OSD's, contained in Appendix E and discussed in Section V, were used to develop not only the operational requirements of the plant but also to develop data for analyzing personnel requirements. The activities of the four operator positions (Foreman, Primary Operator, Filter Operator, and Furnace Operator) were recorded. The OSD's documented what the job included, what the operator did, how he did it, where he did it, and how long it took for him to do it.

Operational/Maintenance Task Matrices

The Operational / Maintenance Task Matrix Technique was formulated and developed during the project to satisfy a need to display the operational and maintenance tasks or functions that were required in the various subsystems of a wastewater treatment system and to identify the skill of the operator performing the function. The Operational/Maintenance Task Matrices for the subsystems - Primary, Activated Sludge, Trickling Filter, Air Flotation, Anaerobic Digestion, Dewatering, Incineration and Ash Disposal, and Chlorination - are contained in Appendix F. The functions or tasks were developed from the OSD's and the preventive maintanance actions documented during the on-site recording phase. Tasks are grouped by the categories: Inspect & Record, Sampling, Normal Operations, Nonroutine Operations, and Preventive Maintenance. Estimated times, based on the OSD recorded times and performance times reported by the maintenance supervisor for the Flint plant, are indicated for each type evolution (hourly, every two hours, etc.). Skill titles for operators are those listed and defined in the U. S. Department of Labor Dictionary of Occupational Titles. Skill ratings for operational tasks are indicated by relative ratings of high, medium, and low within the indicated skill code.

Multiple Activity Chart (MAC)

A Multiple Activity Chart (MAC), Figure 10, was developed to visually display the relationship of the activities of the four operators during a normal eight-hour shift in order to evaluate the utilization of the operators. The MAC displays how each of the operators spends his time during a normal shift. The activities shown in Figure 10 were derived from the OSD's and other on-site observations such as number and duration of meal, relaxation, and assigned cleaning work periods. The dark areas indicate available periods for normal operations which are performed on an "as required" basis such as adjustments to process controls or equipment required by normal changes in the flow rate or other operational factors. The MAC is representative only of what occurs in a normal eight-hour shift. The occurrence of an "as required" event or a "nonroutine" event, such as pipe stoppage, would cause the indicated events to vary from the norm. Included in the dark area is idle time, time when "as required" tasks are not being performed, which could be available for productive work. The tasks and associated times shown in the MAC are true only for the Flint plant. The same tasks performed at another plant, where the layout of buildings and equipment is different, would be displayed somewhat differently.

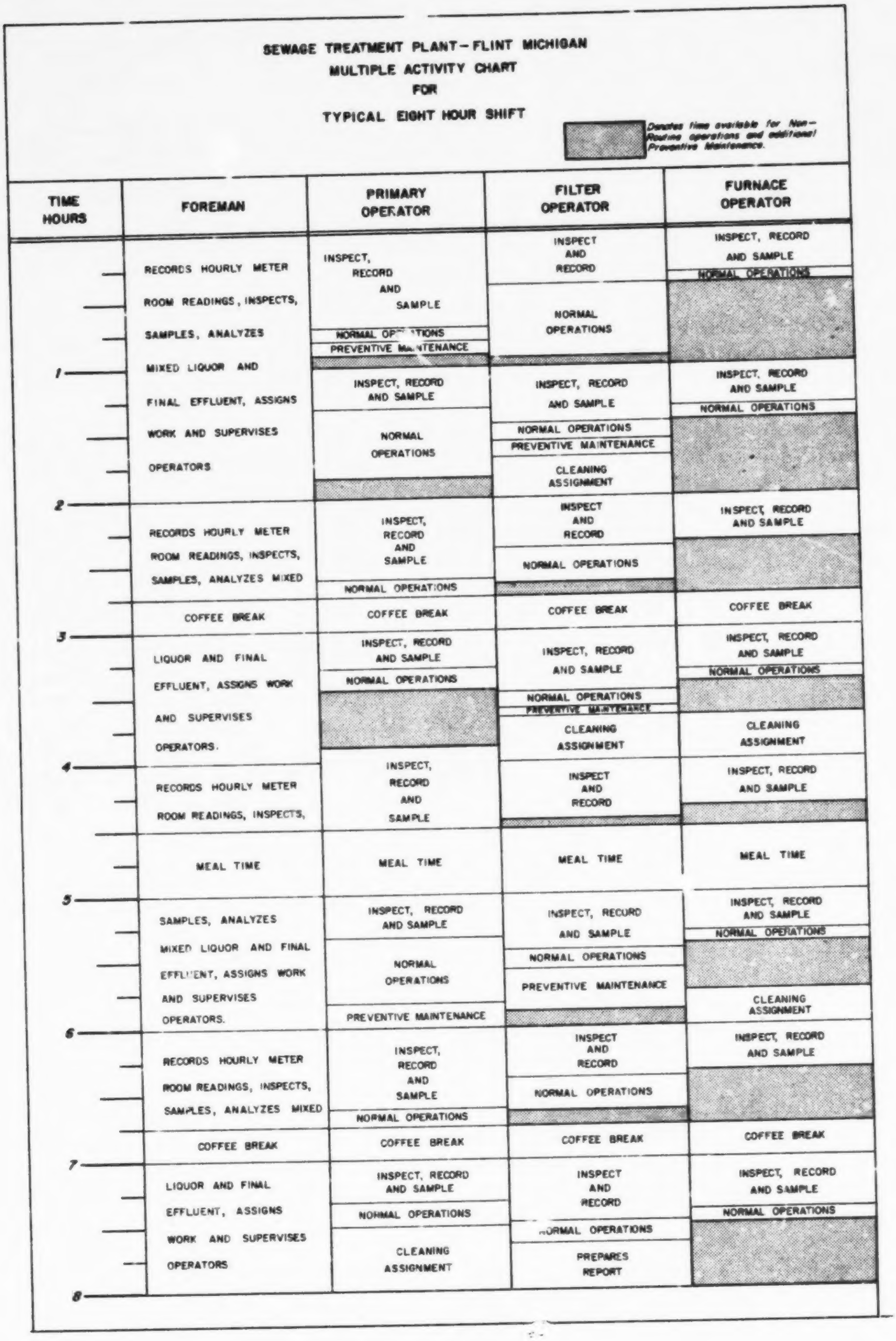


Figure 10
Multiple Activity Chart for
Typical Eight-Hour Shift

FINDINGS

In developing the operational and maintenance personnel requirements for a wastewater treatment plant, four industrial engineering techniques or tools can be applied:

Operational Sequence Diagrams (OSD's)

Operational/Maintenance Task Matrices

Multiple Activity Charts (MAC)

Standard-Time Tables

The above techniques provide an effective combination of methodologies for job analysis to determine personnel requirements for either existing wastewater treatment plants or new plants. In the latter case, the Functional Staging Diagrams, the System/Equipment Staging Diagrams, the Function-Capability-Equipment Matrix, and the Operational/Maintenance Task Matrices would permit the job analyst to develop the OSD's by synthesizing the tasks or functions that would have to be performed.

The four techniques, when used in combination, permit the job analyst to methodically document the individual tasks or functions which comprise the total job. Thus, he is able to eliminate, add, or modify single elements of a job to establish job requirements. He is also able to assess the utilization of the worker and add, delete, or reassign individual tasks or functions. As an illustration, the Operational/Maintenance Task Matrices, Appendix F, indicate that several tasks in the same operational area can be performed by low-skilled operators, while others require medium-skilled operators. Thus, an option exists either for assignment of the low-skilled tasks to an operator-trainee and the medium-skilled tasks to a qualified operator or assignment of all the tasks to a medium-skilled operator. The analyst is assisted in making a decision by selective assignment or reassignment of tasks on a Multiple Activity Chart where he can evaluate the utilization of the operators.

The job analysis of the Flint plant indicates that the operational group consisting of a Foreman, Primary Operator, Filter Operator, and Furnace Operator is an effective organizational component. However, as indicated in the Multiple Activity Chart based on normal activities of a shift, a small amount of time in the "as required" category is available for assignment to other tasks such as additional preventive maintenance functions. In effect, better utilization of operating personnel can be obtained by assigning additional tasks which have no stringent time limitations (example: lubrication of certain equipments each month) to the operator to perform during the "as required" period when no "as required" tasks are in fact required.

The Operational/Maintenance Task Matrices, as developed, proved to be an excellent tool for collecting, organizing, and displaying O&M requirements at an existing plant. The data given in Appendix F, while not strictly applicable to other plants, could serve as a guide to the type of O&M activities generally required.

In addition to the study of staffing levels, personnel effectiveness was also considered. Through interviews with plant management, it was determined that the major problem facing the plant was the high turnover rate. This is not atypical of waste treatment plants although there are notable exceptions. An understanding of this phenomenon can be derived by considering the four factors generally considered important by workers: security (pay); opportunity; recognition; and inclusion. Security, particularly in regard to pay, is a major source of dissatisfaction in waste treatment plants. For a variety of reasons, the wage scale for sewage plant workers is low. Wages, of course, are set by the operating budget which is an indication of the perceived importance of the sewage plant operation by the local governmental unit. That perception is strongly influenced either by society (i.e., the voters) or by the regulatory agency (which also should respond to societal pressures). In most cases, neither has exerted much pressure to hire quality operators. Until that happens, job satisfaction through equitable pay will be elusive.

There are some who argue that certification of operators would increase their professional status. The degree of interest in improving the "lot" of the operator can be deduced by the slow progress of the certification program. As of 1969, 16 states required certification, 30 had voluntary programs, and 4 had none. In those states with voluntary programs, available data showed that less than 50 percent of the operators were certified. In addition, the certification programs which do exist vary widely from state to state; no national organization, such as a Federal agency or the Water Pollution Control Federation (WPCF), has been able to assist the operator by developing a program in which his qualifications are accepted nationwide.

Opportunity for advancement is mainly a function of plant practice. Certainly it would be desirable to have a clearly defined path whereby an employee entering the lower level of the staff "ladder" could, by training, diligence, and application, advance to higher positions. Generally, in-service operator training is practiced in the larger plants. Small plants rely on programs sponsored by the State or by the local section of the WPCF. This can be a hardship for many operators since the courses are normally given at central locations, thus requiring travel expenses and time away from home.

Recognition can be received from two vantage points; in-plant and at-large. In-plant recognition is a function of plant management. However, the societal image of the sewage plant worker, even in this day of "environmental enlightenment," is quite low. Various schemes have been proposed to alleviate this situation including name change (water pollution control plant), uniforms, certification, etc. However, these attempts have been aimed at satisfying the operator. A true change in status will only come when society changes its attitudes toward those who provide basic, necessary, but "dirty," services.

RECOMMENDATIONS

Flint Sewage Treatment Plant

Preventive Maintenance. It is recommended that the Flint plant consider assigning additional preventive maintenance tasks to the operators to be performed during the period allotted to "as-required" operations when such operations are not so required. Such preventive maintenance tasks as weekly or monthly lubrications presently assigned to the maintenance mechanic could be easily accomplished by the operator if it is stipulated that the task should be performed sometime during a given period and not at any specific time. Provisions should be made for reporting the accomplishment of the task to the supervisor.

Operator Turnover. The pay scale at the Flint plant was considered good in relation to those found at other installations. The reasons for the high turnover rate most likely include higher pay available at local industry; poor image associated with sewage plant operation; better chance for advancement at other plants. Whatever the reason, it is imperative that the Flint plant be able to effectively function under these conditions. It is therefore recommended that efforts be expended to develop a rapid and comprehensive in-service training program using techniques that were discussed in previous sections. Of course, existing efforts to improve both the salary and status of the operator should continue. However, without large-scale external input, it is unlikely that a single plant will be able to change conditions significantly.

General

Operational/Maintenance Task Matrices. This technique was devised in the course of this program to identify, group, and display required operation and maintenance functions. It was found that it serves as an excellent link between the equipment list or equipment staging diagram and the OSD. It can be developed using the Function-Capability-Equipment matrix as a basis and thus serve as a direct link to the function oriented design process. It could also be developed from reference tables which would be developed as part of a design manual or guideline.

The Operational/Maintenance Task Matrix, as developed based on recorded data at the Flint plant, should serve as an excellent guide for job analysts responsible for determining personnel requirements for new wastewater treatment systems. However, some doubt exists as to the validity of basing such a document on the observation at only one plant and the validity of basing personnel requirements for different capacity plants on data obtained from a 34 MGD plant. It is recommended that the Operational/Maintenance Task Matrices, contained in Appendix F, be validated for adequacy and applicability to wastewater treatment unit processes or subsystems other than those at the Flint plant, upon which the matrices are based. The effective use of the matrices as a reference document for plant supervisors and others interested in developing personnel requirements is based on the data contained therein being applicable to their specific wastewater treatment system where the configuration and the size of the plant are quite different than the Flint plant. Factors which could affect the matrix data and for which validation at other facilities is required are: (1) design capacity of plant, (2) geographical features, (3) local and state regulations and standards, (4) labor union requirements, (5) system configuration, (6) equipment configuration, (7) equipment manufacturer's requirements, and (8) plant organizational features.

For full validation, it is suggested that at least six wastewater treatment facilities be visited to obtain data. The facilities should be in different regions of the United States and their design capacities should range from 1 MGD to 250 MGD.

Job Analysis. The industrial engineering techniques applied in the job analyses demonstrated that it is possible to evaluate personnel requirements for both new and existing plants on a rational, non-empirical basis. These techniques included the OSD's, MAC, and the Operational/Maintenance Task Matrices supplemented by the use of Standard-Time tables. A question remains as to the degree of effort required to arrive at a complete staffing list as compared to the present empirical approach. If OSD's and MAC's are being prepared for development of Standard Operating Procedures, the approach does not require a large amount of additional effort. It is recommended that an additional study be performed on a plant under design to test the efficiency of this approach.

Maintenance Standards. Although not used during the study, a practical approach is available for establishing standard times on nearly all corrective as well as preventive maintenance work. This approach is called Universal Maintenance Standards (UMS) and stays within the bounds of sound industrial practice. It is economical on both installation and administrative time and cost.

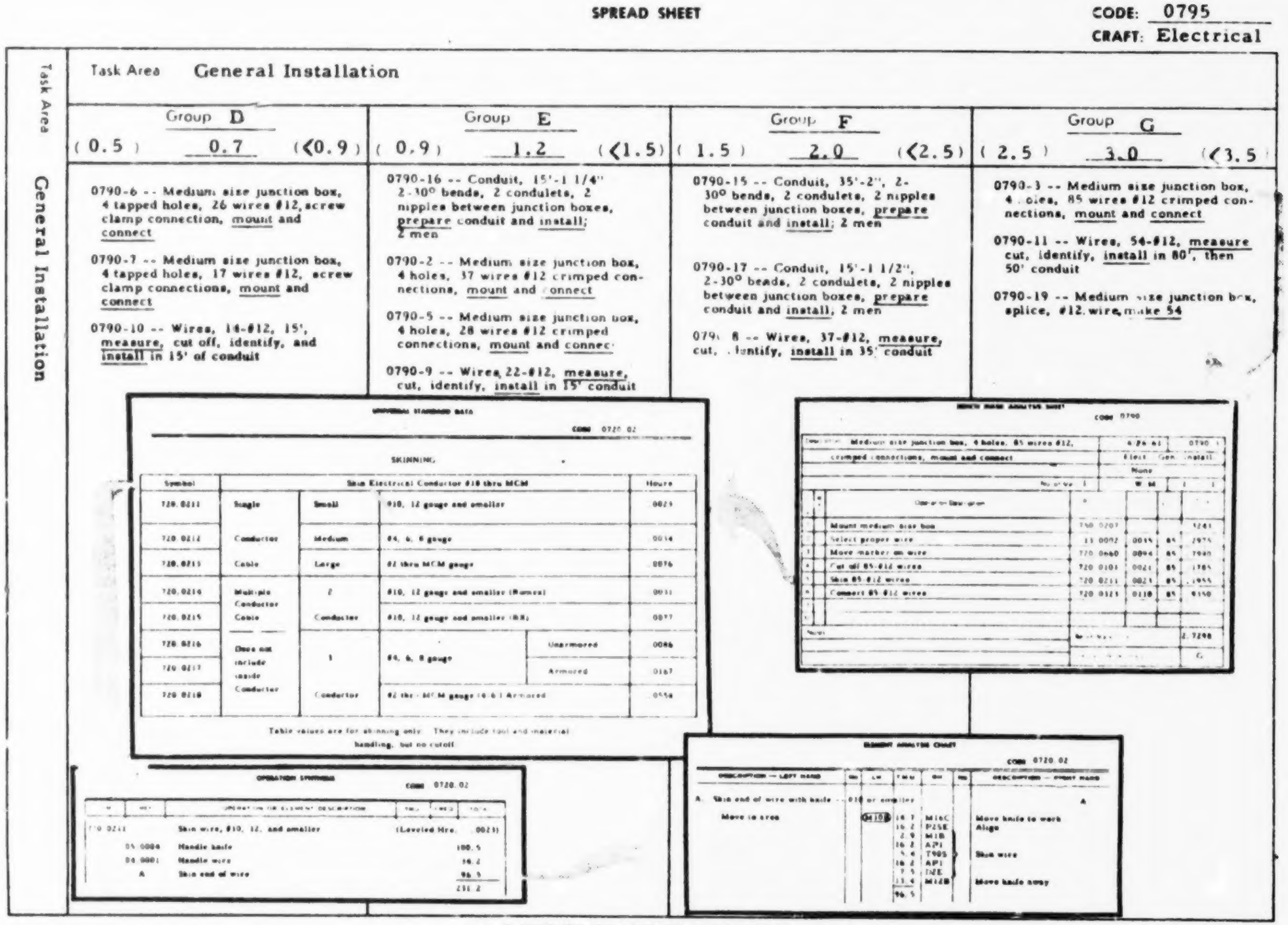
UMS has been used to develop data on thousands of specific jobs. While some of these apply to all industry, others need tailoring only to fit conditions in any specific industry. From these data, jobs have been placed into Standard Work Groupings - one grouping including the jobs within each craft which require a similar range of time for completion.

Figure 11 shows a number of electrical time standards that are presently being used for controlling maintenance work. It also illustrates how the time standards were developed.

Work Sampling. This is a statistical technique employed to determine the proportion of delays or other classifications of activity present in the total work cycle. In maintenance, work sampling is used to determine the effectiveness of the maintenance groups. Secondly, it is often used to rationalize allowances in line with management's agreements or policies on plant activities.

The purpose of this type of study is usually to measure, within reasonable tolerances, the percentage of worker's time that is spent in performing normal work, planning, travelling, delays of various types, idle time, personal time, and other activities. During the course of the study, the performance of the workers can be rated and the working observations can be "leveled" from the worker's performance. When the study is completed, the performance efficiency and labor utilization efficiency can be determined, based upon the methods presently used. These figures will then provide a base point for determining the increase in present operating effectiveness after improved work load planning, operating methods, and management controls are installed.

Multiple Regression Analysis. This is a technique that can be used in conjunction with Work Sampling to establish standards for work tasks and manning requirements.



SPREAD SHEET

CODE: 0795
CRAFT: Electrical

Task Area General Installation

Group D	Group E	Group F	Group G
(0.5) 0.7 (<0.9)	(0.9) 1.2 (<1.5)	(1.5) 2.0 (<2.5)	(2.5) 3.0 (<3.5
0790-6 -- Medium size junction box, 4 tapped holes, 26 wires #12, screw clamp connection, mount and connect 0790-7 -- Medium size junction box, 4 tapped holes, 17 wires #12, screw clamp connections, mount and connect 0790-10 -- Wires, 14-#12, 15', measure, cut off, identify, and install in 15' of conduit	0790-16 -- Conduit, 15'-1 1/4" 2-30° bends, 2 condulets, 2 nipples between junction boxes, prepare conduit and install; 2 men 0790-2 -- Medium size junction box, 4 holes, 37 wires #12 crimped connections, mount and connect 0790-5 -- Medium size junction box, 4 holes, 28 wires #12 crimped connections, mount and connec 0790-9 -- Wires, 22-#12, measure, cut, identify, install in 15' conduit	0790-15 -- Conduit, 35'-2", 2-30° bends, 2 condulets, 2 nipples between junction boxes, prepare conduit and install; 2 men 0790-17 -- Conduit, 15'-1 1/2", 2-30° beads, 2 condulets, 2 nipples between junction boxes, prepare conduit and install, 2 men 079 8 -- Wires, 37-#12, measure, cut, identify, install in 35' conduit	0790-3 -- Medium size junction box, 4 holes, 85 wires #12 crimped connections, mount and connect 0790-11 -- Wires, 54-#12, measure cut, identify, install in 80', then 50' conduit 0790-19 -- Medium size junction box, splice, #12 wire, make 54

Task Area General Installation

H B MAYNARD AND COMPANY INCORPORATED

Figure 11
Example of Time Standards for Electrical Maintenance

SECTION VIII

QUALITY CONTROL IN WASTEWATER TREATMENT PLANTS

ELEMENTS OF QUALITY CONTROL

Quality control is defined as those functions which must be carried out in order to ensure that the desired quality objectives for the product are being met. Within this definition, there are several factors which must be considered including a definition of quality objectives, means of measuring quality, ability to control the manufacturing process, and communications for feedback and proper dissemination of data.

In most industries, quality goals are identified by management after consideration of consumer preferences, sensitivity of demand to quality, effect on product cost of various levels of quality, etc. Once the parameters of quality have been defined, the process required to produce a product capable of meeting these standards is devised. Included in the process development are provisions to control or vary the process so that positive control over product quality is possible during production. Measurement techniques must be devised to accurately determine whether quality standards are being met. Effective communications must be set up to report the results of quality measurements back to those who are responsible for meeting quality goals and those capable of controlling the process. Thus, the various required elements of a quality assurance program can be described as follows:

Quality Goals - Clear identification of quality requirements; identification of significant measurable parameters and acceptable range of values for these parameters; knowledge of "cost" or "profit" penalties associated with failure to meet goals.

Process Control - Design such that quality can be controlled, if required; definition and assignment of responsibility for quality in production area; clear definition of the meaning of quality specifications; proper incentive in production group; rejected product salvage if possible.

Measurement - Ability to accurately measure quality parameters; adequate frequency, duration, and technique of sampling; independent sampling and measuring group; independent interpretation of results; incentive for measurement personnel to be accurate and independent.

Communication and Feedback - Data relay to those responsible in both process and management; rapid turnaround of information; adequate means of organizing and displaying data for short and long term performance.

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From the above, it can be seen that quality control must be practiced in all phases of production activity: design, equipment specifications, purchasing, operations, maintenance, etc. One aspect of quality control that is important in regard to waste treatment systems is quality assurance, which is concerned with presenting to management summarized facts on quality performance. Management in this sense can be considered both in regard to the plant and the regulatory agency.

Work Study can be applied in two basic modes: (1) study of operator routines for sampling and operating report preparation; (2) critical examination of overall quality control programs. Operator routines were discussed in a previous section. This section will deal with the examination of current waste treatment practice as it relates to quality control elements.

DISCUSSION

Quality Goals

Industrial quality goals are established after consideration of the market, costs, technical feasibility, etc. In the sewage treatment field, the quality goals are set by the regulatory agency which also acts as the purchasing agent for society. That is, the regulatory agency decides, after input from a variety of groups such as voters, citizen groups, other agencies, etc., what quality product it will require. A difficulty arises in that there are a number of ways in which the quality goals can be expressed: concentration of pollutants in effluent; absolute amount of pollutants in effluent (lb/day); effect on receiving stream; and provision of certain equipment specifications of "secondary treatment" or equivalent. The last two approaches offer interesting analogies in industry. Specifying quality by process equipment is analogous to an automobile manufacturer stating that his quality requirements for steel are satisfied as long as he knows that it comes from an open hearth furnace. Acceptance of quality based upon the effect on receiving streams is theoretically sound, but if it is the sole quality control requirement, it is unwieldy. This would be analogous to buying tires strictly on the basis of the tread wear achieved rather than on readily measured parameters that are related to tread wear. There is too long a time lag between the purchase and the manifestation of acceptable or unsatisfactory quality.

Another problem with quality standards as they are usually defined for sewage treatment is the failure to accurately reflect the normal variations in treatment performance. The quality of effluent from biological treatment plants is never constant. All significant parameters vary considerably due to several reasons, some of which are stated on the following page.

Constantly varying raw BOD, suspended solids, etc.

Constantly varying hydraulic loads

Cyclical nature of biological reactions

Minor equipment and operator malfunctions

Varying ambient and waste contribution which
can inhibit or alter biological kinetics or loading

With all of these factors, it is not surprising that there is considerable variation in effluent quality, even in well-run plants. Studies (Refs. 10, 11) have shown that the coefficient of variation of BOD and suspended solids through activated sludge plants actually increases. While the existence of these uncontrolled variations is known, the quality goals as set by most regulatory agencies do not reflect this reality. Thus, a designer or manager can be faced with a "not to exceed" standard which means that he must operate the plant at an average efficiency much higher than the limit. Quality goals which are stated in terms of average quality do not reflect the variability in effluent; short term variations can exert very significant effects on receiving waters. What would be desirable is a clearer means of defining quality goals; an approach which perhaps not only specifies the allowable average content of pollutant but also a maximum and an indication of allowable variation stated in a statistical framework; for example, a frequency distribution curve based upon a given time span. The question remains whether the state-of-the-art of biological waste treatment is advanced to the degree where plants can be designed on this basis. However, if more stringent performance specifications are promulgated, there may be equipment or process changes that can be incorporated to satisfy them. For example, raw waste equalization ponds or tanks have long been used in industrial waste treatment to dampen flow rates and waste variability. Because of a lack of incentive, they have not been widely accepted in the municipal field. Raw waste bypass is another example; if it were unacceptable to bypass raw sewage due to process overload or equipment malfunction, means would be found (redundant elements, holding ponds, etc.) to meet this requirement. If it is not required, it will not be done.

Process Control

Conventional biological treatment plants are simple in terms of basic processes: contact waste with a suitable concentration of viable bacteria for an adequate time in the presence of dissolved oxygen and remove the bacteria from the treated waste by settling before discharge. In terms of operation there are relatively few means of changing or controlling the process, the two major parameters being the food-to-microorganism (F/M) ratio and the dissolved oxygen content. For conventional activated sludge plants, the dissolved oxygen (D.O.) content should be above a certain minimum, usually 1 mg/ℓ. Benefits accrued from high D.O. levels are normally not worth the added power cost. An exception to this is the "UNOX" system which utilizes pure oxygen to achieve very high D.O. levels. Thus, the main operating control for removing organic material from sewage is the food-to-microorganism ratio. This ratio is a function of incoming BOD (variable), detention time (varies inversely with inflow rate), and microbial population (mainly dependent upon the recycle rate of settled sludge from secondary clarifiers as well as the solids concentration of settled sludge). The primary controlling technique for ensuring that the process is functioning as designed is the amount of sludge recycled. Note that in order for the process to function according to theory, the F/M ratio must be kept within a relatively narrow range which is characteristic of that given plant. Thus, in the face of varying inflow rates and BOD concentrations, control of the amount of recycled sludge is the only tool to ensure the proper food-to-microorganism ratio.

Most plants control recycle rate on the basis of inflow volume (see Figure 7 for Flint); others attempt to control the F/M ratio by measuring the mixed liquor solids content and adjusting the recycle rate as needed. There are difficulties with both methods: (1) the BOD (food) of the incoming waste is assumed constant, which is not true; (2) either mixed liquor suspended solids or volatile suspended solids are used as an approximation of reliable microorganisms, both of which can be very misleading since the total or volatile suspended solids determination does not differentiate between microbial and inert solids. Thus, the only major method of controlling the waste treatment process, the F/M ratio, is hampered by measurement difficulties. The BOD test takes too long to be of on-line use; and the suspended solids analysis is indirect.

Measurement

Quality goals are only meaningful if the goals can be expressed by parameters that can be easily and accurately measured. Essentially all effluent quality goals that are applied in the wastewater field are mainly concerned with five-day BOD and suspended solids. It is well known that the five-day BOD test suffers many weaknesses, including: poor reproducibility; questionable accuracy; long analysis time; subject to interferences; may not represent true conditions in either the treatment plant or the receiving stream. Because it is the only bioassay type technique that is relatively easy to perform and because of historical precedent, it remains the primary parameter for quality measurement for treated sewage. The effectiveness of the BOD test for on-line quality control is essentially nil. Often, by the time a substandard BOD is discovered (5-6 days), the problem has passed. If remedial actions are taken, it would be another 5-6 days until the results of those actions were known. Thus, the current quality measurement technique of greatest significance, BOD, is of no value in a quality control program since it provides little or no feedback data for timely process control. In a quality control minded industry, this would be an intolerable situation.

There are several reasons why a more effective quality analysis has not been developed. Perhaps the most important is the lack of incentive for development, purchase, and use. As long as strict quality control is not required, sewage treatment plants will be reluctant to purchase additional analytical hardware or to hire skilled personnel. At the same time, instrument manufacturers are reluctant to invest large amounts of money to develop an instrument or technique for which there is no market. For any product, the quality control exerted by the manufacturer will only be that required by the customer since quality control costs money.

Communications and Feedback

In order for a quality control program to function properly, relevant data must be rapidly relayed to those responsible for quality decisions as well as those who are able to control the process. In the waste treatment field, these parties correspond to the regulatory agency and the plant management. Communication of operating data can be effective depending upon the management practices. At Flint, several forms were prepared and circulated daily containing the results of a large number of analyses on various parameters of interest including influent, effluent, and mixed liquor sludge characteristics. While these data are very helpful in relation to the economics and the operation of certain equipment, such as the vacuum filter, it does not enable plant management to exert direct and complete control over the quality of the effluent, due to the reasons previously discussed.

Communication of data to the regulatory agency varies considerably from state to state. One study in 1969 (Ref. 12) indicated that only 44 states require submission of operating reports. Of these states almost 40 percent of the plants did not submit reports during 1969. Data requirements also vary widely. Michigan requires extensive operating data from Flint, some of which are only indirectly related to the quality of the effluent such as the pounds of chemicals applied to the vacuum sludge filters. A significant amount of time is spent by Flint plant management in fulfilling state data requirements. There are large differences in the use of the data, once reported. Michigan evidently reviews the data from Flint carefully and questions results which are out of the norm. Some states merely file the data for future use, if required. In few cases are the analyses as reported checked by the regulatory agency or an independent laboratory for accuracy. Normally, there is little assurance that the plant analytical techniques are correct.

The reasons for the wide variation in approach by regulatory agencies are subject to conjecture. Some may be: lack of funds for staffing; lack of qualified manpower; political considerations; and differences in philosophy on the efficacy of close regulation.

CONCLUSIONS AND RECOMMENDATIONS

Based upon comparison with industrial practice, it is concluded that the quality control programs associated with waste treatment plants are generally poor or nonexistent. The responsibility for this situation does not lie with the plants alone but also with the state-of-the-art and the various approaches used by regulatory agencies. If a consistently high quality effluent is deemed desirable, then new knowledge, approaches, and techniques must be developed including:

> Normal Variations in Effluent Quality. Consideration should be given to projects to identify the normal variation in effluent quality that can be expected in biological treatment plants, exclusive of equipment or operator failures.
>
> Expression of Quality Goals. Consideration should be given to development of quality goals that more adequately reflect the variability inherent in biological treatment systems.
>
> Process Modifications. Cost/benefit studies should be initiated on the feasibility of incorporating additional process steps to minimize variations in sewage flow and strength as well as means to prevent release of substandard effluent.
>
> Process Control. True quality control will not be possible until techniques are developed to allow on-line process control and accurate monitoring of effluent quality. In order for this to happen, incentives for development are required at the federal level. It is recommended that a state-of-the-art study of on-line control and quality monitoring be supported. Included should be consideration of alternate incentive generating actions such as more stringent operation requirements, financial support of equipment development, etc. Until this is accomplished, it is doubtful that biological waste treatment systems will be able to produce consistently acceptable effluent.
>
> Analytical Procedures. Dissatisfaction with the BOD test is not new. Unless strong pressure is exerted to replace it with a more meaningful and acceptable analysis, changes will be very slow. A state-of-the-art study of bioassay or equivalent analyses is recommended to identify promising approaches and to investigate alternative means of promoting the development and use of better techniques.
>
> Reports and Enforcement. There is a wide variation in reporting requirements between the state regulatory agencies. The advisability and practicability of uniform reporting requirements for both state and federal use should be investigated.

SECTION IX

APPLICATION OF RELIABILITY AND MAINTAINABILITY EVALUATION TECHNIQUES

INTRODUCTION

Reliability and maintainability (R&M) evaluation techniques (see Section III for definitions) were originally formulated to solve serious military problems caused by equipment failures during wartime missions. In most cases, such missions were accomplished during limited and predictable time periods. Therefore, the reliability effort to solve equipment failure problems was directed towards making complex equipment more reliable by increasing the probability that it would not fail during a specified "mission time" period. Complementary maintainability techniques were directed toward reducing to a minimum the average time needed to repair an equipment item if and when it did fail. The combination of the R&M characteristics of an equipment item determined the fraction of operating time the equipment was available, or what is referred to as equipment availability.

The "mission time" of a wastewater treatment plant is a continuum because the plant is in operation 24 hours a day, 7 days a week, 365 days a year. The reliability effort for a wastewater treatment plant should be directed toward preventing the occurrence of an equipment failure or combination of equipment failures which would result in a failure of the plant as a whole. To attain this objective, equipment reliability and maintainability characteristics, standby equipment requirements, and preventive and corrective maintenance practices must be carefully integrated into a well-planned man-machine system.

A primary objective of this program was to attempt to establish a correlation between equipment R&M characteristics and the capability of a wastewater treatment plant to achieve its desired goals. Plant goals are: (1) to continuously produce an effluent of acceptable quality; and (2) to operate in an efficient and economic manner. The approach used was to conduct a reliability and maintainability evaluation of a "typical" conventional plant applying adaptations of techniques which have been used successfully to analyze military systems. The Sewage Treatment Plant in Flint, Michigan, was selected for this purpose. The evaluation included development of a mathematical reliability model using data obtained at that plant. This model was the basis for evaluating the effects of equipment reliability, maintainability, and availability on the plant's operation.

Reliability and maintainability techniques used during the analysis and which can be applied in plant design and maintenance planning are described in the succeeding paragraphs. The purpose and sequence in which each technique is applied in the evaluation process are summarized in Figure 12.

The first part of the process is to establish a basis for the evaluation by describing:

> Functions which must be performed by the system. Functional Staging Diagrams in Appendix A are used for this purpose.
>
> Equipment which is needed to perform each function. System/Equipment Staging Diagrams in Appendix D are used.
>
> The frequency and time duration that each part of the system performs its function without interruption must be determined. Observed or derived estimates of equipment operating requirements in the system are used. Although a wastewater treatment plant must perform its function continuously, each equipment is not necessarily in continuous operation. Therefore, certain interruptions in equipment operation do not interrupt the plant's treatment function; certain interruptions in equipment operation, or combinations thereof, will interrupt the plant's function while others may not; and other interruptions in equipment operation will not interrupt the plant's function unless they continue too long.

The second part of the evaluation process is to compare system R&M characteristics with system R&M requirements and determine courses of action necessary to reconcile their differences. This is accomplished by analyzing:

> The system's capability to function properly without interruption. Reliability block diagrams, failure data, and reliability and maintainability calculations are used to determine the frequency and cumulative effect of equipment failures on the plant's treatment function.
>
> Reasons for equipment failures and alternative actions which may be taken to increase the length of time between failures or to compensate in some manner for them. Failure Modes and Effects Analysis is performed.
>
> Determine the most attractive alternative actions and the effects of selected alternatives in improving the reliability and maintainability of the system. Reliability block diagrams and calculations are used.

Technique descriptions are organized under three topics: modelling, evaluation, and application; the elements of each topic are shown in Figure 13.

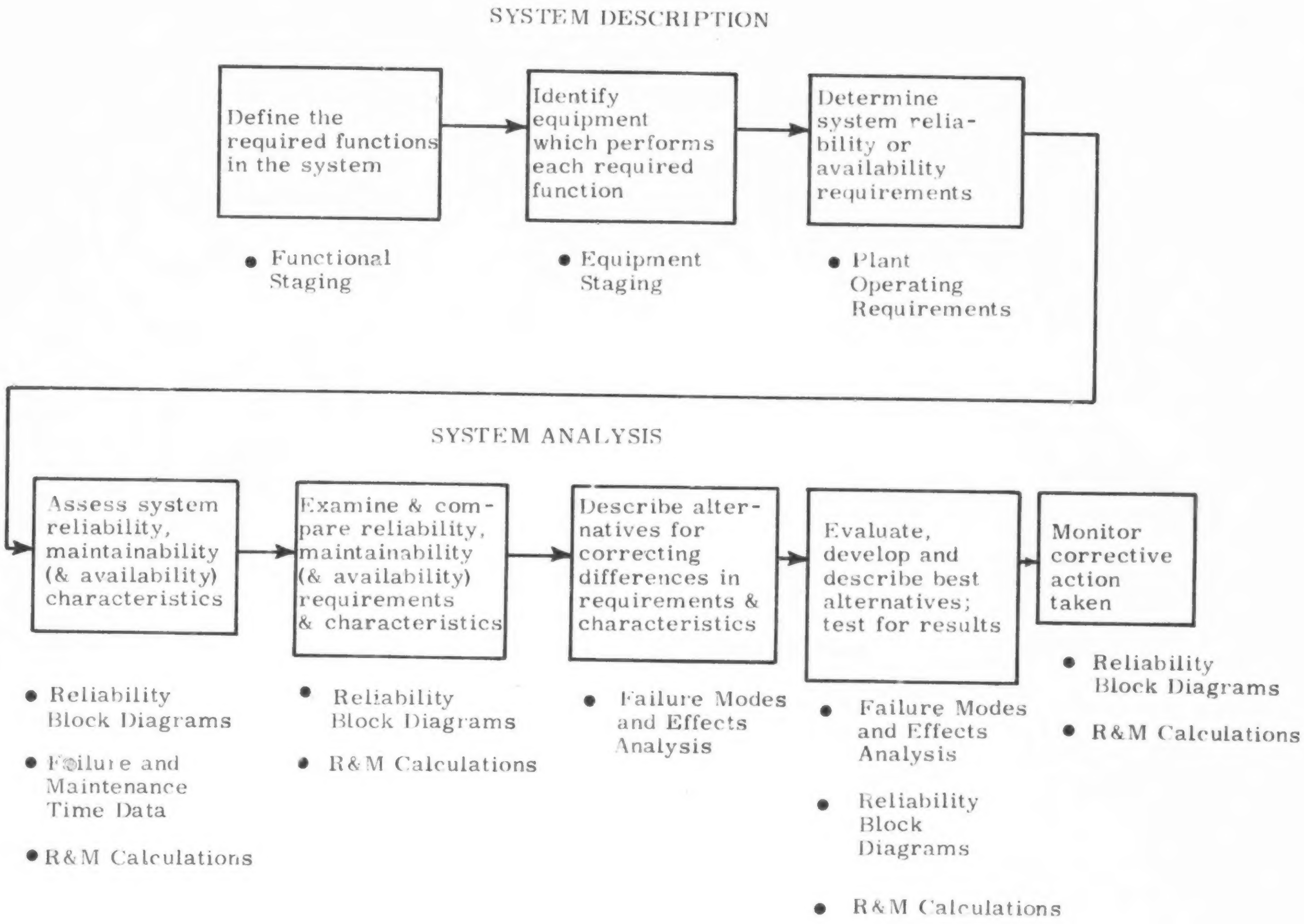

SYSTEM DESCRIPTION
Define the required functions in the system
• Functional Staging
Identify equipment which performs each required function
• Equipment Staging
Determine system reliability or availability requirements
• Plant Operating Requirements
SYSTEM ANALYSIS
Assess system reliability, maintainability (& availability) characteristics
• Reliability Block Diagrams
• Failure and Maintenance Time Data
• R&M Calculations
Examine & compare reliability, maintainability (& availability) requirements & characteristics
• Reliability Block Diagrams
• R&M Calculations
Describe alternatives for correcting differences in requirements & characteristics
• Failure Modes and Effects Analysis
Evaluate, develop and describe best alternatives; test for results
• Failure Modes and Effects Analysis
• Reliability Block Diagrams
• R&M Calculations
Monitor corrective action taken
• Reliability Block Diagrams
• R&M Calculations

Figure 12
Reliability and Maintainability Evaluation
Flow Process Elements

A. Modelling

- Reliability Block Diagrams
- Data Analysis
- Reliability & Maintainability Calculations
- Reliability & Maintainability Relationships

B. Evaluation

- Reliability, Maintainability, Availability Assessments
- Failure Modes and Effects Analysis

C. Application

- Corrective Action
- Design Optimization
- Maintenance Planning

Figure 13
Elements of the Reliability and Maintainability Evaluation Techniques

MODELLING TECHNIQUES

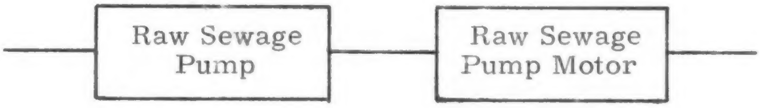
Reliability models usually consist of two elements -- block diagrams and calculations. Typically, they are used to describe the probability that a system will perform its function for a specified time without failing and thereby accomplish its objective. Models are an extension of function and system/equipment analysis into the operating time domain. They are used as the basis for determining equipment and operational relationships and quantities of equipment needed to assure sufficient system flexibility in predictable equipment failure situations. Since calculations in modelling are made using records of equipment failures and malfunctions during operations or tests, models can be used for planning equipment maintenance to prevent and correct equipment failures and malfunctions.

Reliability Block Diagrams

Reliability block diagrams have been developed for the Flint plant to demonstrate this technique and show the dependency relationship of equipment, elements, and subsystems in carrying out the wastewater treatment process. Typically, these redundant or nonredundant relationships are diagrammed as being in "series," "parallel," or "series-parallel" combinations.

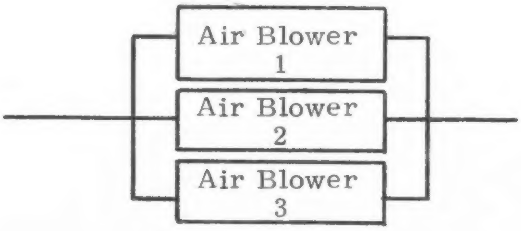
In a series combination, each equipment must successfully perform its function for the entire combination to perform successfully. A parallel combination contains "standby" equipment which takes over performance of a function for the equipment which fails.

Example: Series Combination



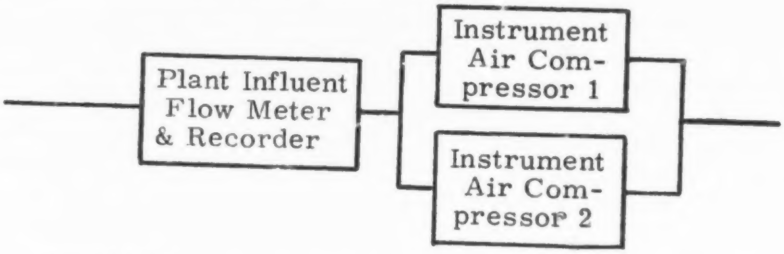
The raw sewage pump and its motor are dependent upon the performance of one another in order for the combined functions they perform to be a success.

Example: Parallel Combination



Blowers 1, 2, and 3 are installed so that any one of the three can perform the air delivery function. When blower 1 is operating, either blower 2 or 3 is available to supply air in place of number 1 should it fail.

Example: Series-Parallel Combination


Plant Influent Flow Meter & Recorder
Instrument Air Compressor 1
Instrument Air Compressor 2

The air-actuated flow meter and recorder are in series with two air compressors, one of which is needed to provide air to the meter and recorder; the other is installed in parallel with the first in case it fails. The flow meter and recorder and either one or the other instrument air compressors are in series because they are needed to indicate and record plant influent flow information.

Reliability block diagrams for the Flint plant were developed using these basic diagramming procedures and information contained in the functional and equipment staging diagrams for the plant. Diagrams of the plant's subsystems and elements are given in a later subsection on R&M calculations. (Formulas for the R&M calculations are included in Appendix H.)

Data Analysis

In order to perform reliability and maintainability calculations, certain equipment performance data are required. The following paragraphs describe how raw data are processed into a form which permits them to be used in such calculations.

Raw data were available at the Flint plant in the form of descriptions of "Equipment Malfunctions" which are reported chronologically by operating personnel; a sample of the form used for these reports is shown on sheet 1 in Appendix G. Data for a one-year period, July 22, 1970 to July 21, 1971, were selected for analysis. Since the operators must make such reports for corrective maintenance to be performed, there is a relatively high degree of confidence that all equipment malfunctions discovered by the operators during their inspection and operation of equipment were entered on the forms during the data period.

During the data reporting period, 711 equipment "problems" were reported. Each problem description was reviewed to determine whether it represented an equipment "failure" or an equipment "malfunction." The following definitions were used in making these determinations:

Failure

An equipment problem which prohibits the equipment from being kept in operation or prohibits the equipment from performing its required function. When an equipment failure occurs, the satisfactory accomplishment of the equipment's function is lost to the plant process until corrective maintenance is performed.

Malfunction

An equipment problem which does not prohibit the equipment from being kept in operation and does not prohibit the equipment from performing its design function acceptably. However, a malfunction may result in inconvenience or inefficient operation.

During the review of each problem described in the data, each "failure" and "malfunction" was determined, and the specific equipment involved was identified by its System/Equipment Staging code number. After the review was completed the quantities of "failures" and "malfunctions" were totalled for each equipment code number. A sample Work Sheet is shown on sheet 2 in Appendix G. Summaries of these data were recorded in columns (3) and (4) on data sheets, samples of which are in Appendix H. The following determinations were made from the problem descriptions for the one-year period:

Equipment failures	-	302
Equipment malfunctions	-	202
Problems not affecting the plant process (e.g., light bulbs burned out)	-	207
Total:		711

Calculations were performed using the previously described data. Techniques used in making the calculations are described below. The Sample results of calculations performed are summarized on sheets contained in Appendix H.

Equipment operating hour records are maintained on relatively few items of equipment at the plant. To provide a basis for subsequent calculations of MTBF (mean time between failures), estimates of the number of hours each equipment item is typically operated per day were obtained from qualified plant operator personnel. Total operating hours per year for each equipment code number was calculated using the following formula:

Total equipment operating hours (per year) =

Qty. of equipment operated each day (equipment items)
x estimated no. of operating hrs per day (hrs/day) x
365 (days/year) = hrs/year

Example: (Pumping and screening instrument air compressors)

Total equipment operating hours (per year) = 2 (equipment items)
x 12 (hr/day) x
365 (days/year) = 2 x 12 x 365 = 8760 hr/yr

Estimates of MTBF (mean time between failures) and MTBM (mean time between malfunctions) were then calculated for each equipment using the following formulas:

$$\text{MTBF} = \frac{\text{Total equipment operating hours (per year)}}{\text{No. of failures (per year)}}$$

$$= \text{Operating hours per failure}$$

$$\text{MTBM} = \frac{\text{Total equipment operating hours (per year)}}{\text{No. of malfunctions (per year)}}$$

$$= \text{Operating hours per malfunction}$$

Example: (Pumping and screening instrument air compressors)

$$\text{MTBF} = \frac{\text{Total equipment operating hours (per year)}}{\text{No. of failures (per year)}}$$

$$= \frac{8760}{1} = 8760 \text{ hr} \quad (\text{"between failures"})$$

$$\text{MTBM} = \frac{\text{Total equipment operating hours (per year)}}{\text{No. of malfunctions (per year)}}$$

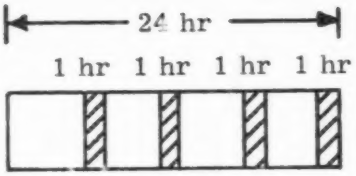
$$= \frac{8760}{2} = 4380 \text{ hr} \quad (\text{"between malfunctions"})$$

Some equipment is only operated part of the time. To convert values of MTBF and MTBM of "part-time" equipment to system operating hours, the equipment's MTBF and MTBM are divided by the percentage of time the equipment operated in the system. The percentage value in this calculation is referred to as "duty cycle." In the evaluation, a typical equipment operating day was used as a basis for calculating duty cycles. The formula used is:

$$\text{Duty cycle} = \frac{\text{No. of hours equipment operates/day}}{\text{No. of hours system operates/day}}$$

Example: Single Equipment

Note: ▨ Denotes equipment operating period.



Bar Screen Rake

$$\text{Duty cycle} = \frac{\text{No. of hr bar screen operates/day}}{\text{No. of hr system operates/day}}$$

$$= \frac{4 \text{ hr}}{24 \text{ hr}} = 0.17$$

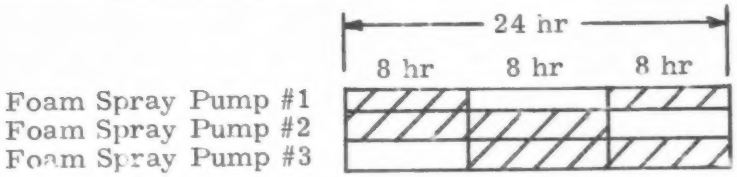
MTBF (adjusted to system hours)

$$= \frac{\text{MTBF for continuous equipment operation}}{\text{Duty cycle}}$$

$$= \frac{365 \text{ hr}}{0.17} = 2147.1 \text{ hr}$$

There were no malfunctions recorded for the bar screen rake during the reporting period; however, calculations for converting MTBM from "equipment time" to "system time" are performed in the manner as above for MTBF.

Example: Multiple Equipment



$$\text{Duty cycle} = \frac{\text{No. of hr foam spray pumps operate/day}}{\text{No. of hr system operates/day}}$$

$$= \frac{8 \text{ hrs(F.S.P. 1\&2)} + 8 \text{ hrs(F.S.P. 2\&3)} + 8 \text{ hrs(F.S.P. 1\&3)}}{24 \text{ hrs}}$$

$$= \frac{24 \text{ hr}}{24 \text{ hr}} = 1.00$$

MTBF (adjusted to system hours)

$$= \frac{8760}{1.00} = 8760$$

MTBM (adjusted to system hours)

$$= \frac{\text{MTBM for continuous equipment operation}}{\text{Duty cycle}}$$

$$= \frac{5840}{1.00} = 5840$$

Certain reliability and maintainability calculations are facilitated using equipment failure rates in place of MTBF. Failure rate (λ) is the rate at which failures occur during an interval of operating time and is the reciprocal of MTBF; it is normally expressed in failures per equipment (or system) operating hour.

Example:

$$\lambda = \frac{1}{\text{MTBF}}$$

$$\lambda \text{ Foam spray system pumps} = \frac{1}{8760}$$

$$= 0.114 \times 10^{-3} \text{ failures per system operating hour}$$

RELIABILITY AND MAINTAINABILITY CALCULATIONS

With equipment series and parallel relationships displayed in reliability block diagrams and process data available, reliability and maintainability calculations can be made. The results of these calculations provide engineering and maintenance planning information and can be used to demonstrate the degree to which a new plant design relates to the general reliability requirements contained in the "Federal Guidelines." The same basic calculations can be used to make design and management decisions on practically all matters affected by reliability and maintainability.

Reliability Calculations

The fundamental calculation involves what is referred to as the "product law of reliabilities" which is that the reliability of a system (R_s) is equal to the product of the reliabilities of its subsystems in series, i.e.,

$$R_s = R_1 \cdot R_2 \cdot R_3 \cdot \cdot \cdot \cdot \cdot \cdot R_n$$

(A method for converting parallel subsystems to an equivalent series subsystem is given later.)

The result of the calculation is a numerical expression of the probability that the system will perform its intended function for a specified length of time without failing. Note that the product law implicitly states that the success of the system is possible only when all subsystems are functioning properly. Thus, if one subsystem fails, the entire system fails.

A formula for calculating subsystem reliability (R_1, R_2, etc.) is:

$$R = e^{-\lambda t}$$

where:

λ = subsystem failure rate

t = system operating time

In using this formula, it is assumed that component failures occur at random intervals and that the expected number of failures would be the same for equally long periods of time during the useful life of the component. In other words, the component's failure rate is assumed to be constant over equally long periods of time. In lieu of evidence that a component's failure rate is not constant, this formula is generally used because of its relative simplicity. In the case of the Flint plant, a graph of cumulative equipment failures vs. cumulative plant operating hours plotted as almost a straight line with the slope indicating the failure rate for the composite plant system to be a constant (Refer to Figure 14).

Example: Subsystem Reliability Calculation

$\lambda = 0.114 \times 10^{-3}$ failures/system operating hour

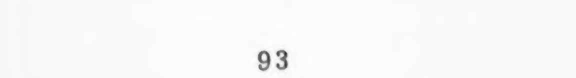
t = 720 system operating hours (one calendar month)

$$R = e^{-(0.114 \times 10^{-3} \times 720)} = 0.921$$

The results of this calculation could be expressed, "There is a 92 percent probability that the subsystem will perform its function for 720 operating hours without failing."

Example: System Reliability Calculations for Subsystems in Series:

Block Diagram



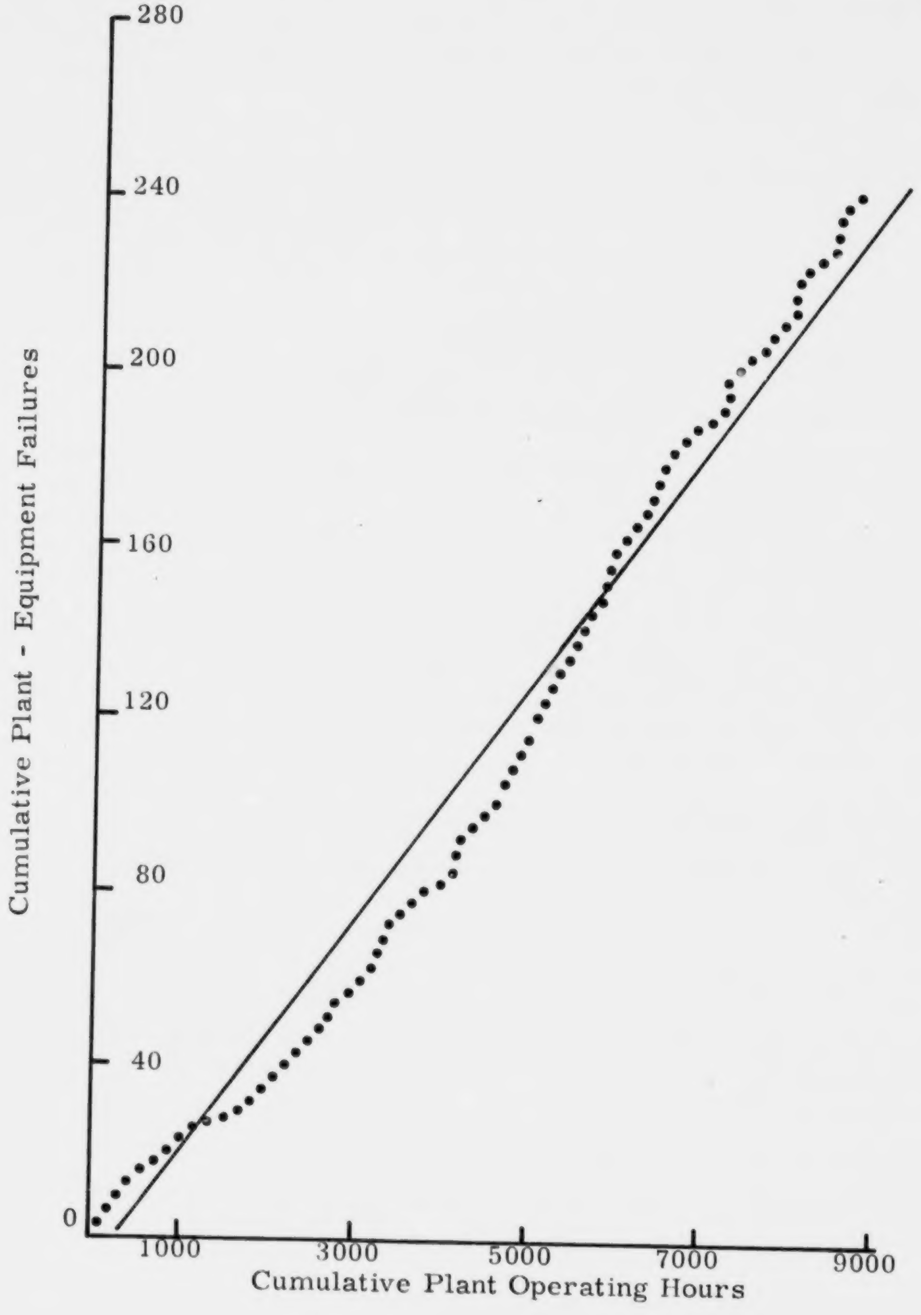


Figure 14
Failures vs. Operating Hours

Subsystem reliabilities are:

$R_1 = 0.921$

$R_2 = 0.683$

$R_3 = 0.849$

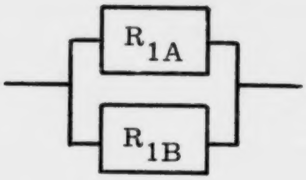
Calculations

System reliability, $R_s = 0.921 \times 0.683 \times 0.849 = 0.534$

For Subsystems in Parallel:

In making this calculation, parallel or redundant subsystems can be reduced to an equivalent "composite subsystem" so that the system equation for expressing the "product law of reliabilities" can be used. The following is an example of the manner in which this can be done:

Block Diagram



Subsystem reliabilities are:

$R_{1A} = 0.921$

$R_{1B} = 0.921$

Calculations

In this case, the equation used for calculating the reliability value of the equivalent "composite subsystem" is:

$R_S = R_{1A} + R_{1B} - R_{1A} R_{1B}$

$R_S = 0.921 + 0.921 - (0.921)(0.921)$

$R_S = 0.994$

It should be noted that, in this case, a single subsystem has a reliability of 0.921, whereas two in parallel have a higher reliability of 0.994.

Approximation formulas have been derived to facilitate calculating reliability values for parallel subsystems. These formulas are in Appendix I. Reliability models at the system and subsystem levels for the Flint plant are shown in Figures 15 and 16. Element level models are not included. A one-month operating period (720 hours) was selected for making reliability calculations and analyses of the distribution of reliability values of the different items of equipment.

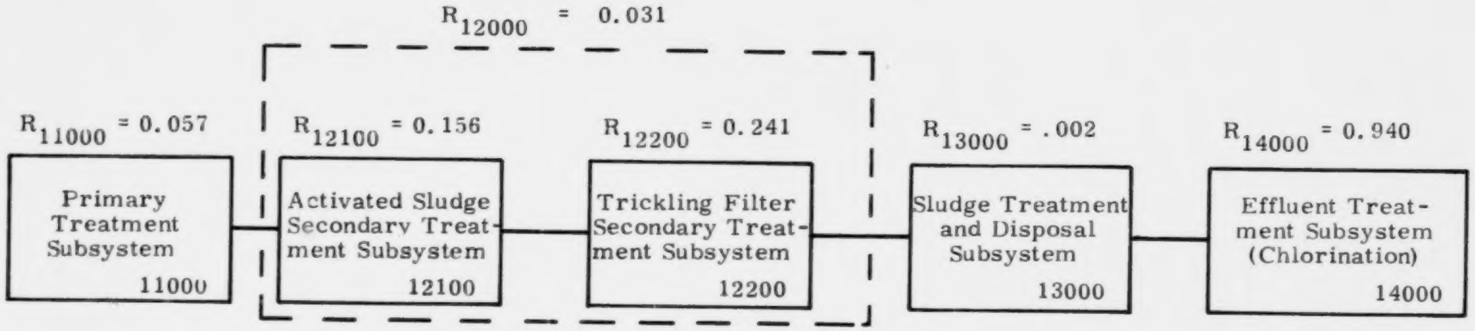
System reliability values derived and shown in Figure 15 indicate that there is a very low probability that the plant could continuously operate for one month without a failure of at least one of its components. By far the highest probability of failure would be in the sludge treatment and disposal subsystem. The order of decreasing probability of success is: chlorination, primary treatment, secondary treatment, and sludge treatment for this particular plant. The order would probably hold true for any increment of operating time. The following tabulation contains the reliability values for each subsystem for several selected plant operating periods.

Reliability Values for Selected Plant Operating Times

Subsystem	720 hr (30 days)	120 hr (5 days)	64 hr (5 pm Fri. to 9 am Mon.)	24 hr (1 day)	8 hr (1 shift)
Primary Treatment	0.057	0.620	0.775	0.908	0.969
Secondary Treatment	0.031	0.560	0.734	0.890	0.962
Sludge Treatment & Disposal	0.002	0.354	0.575	0.813	0.933
Chlorination	0.940	0.990	0.995	0.998	0.999
Plant	0.00000331	0.122	0.326	0.656	0.860

This tabulation illustrates the higher values of reliability during the shorter plant operating periods.

It is important to note that the reliability model assumes that overall system failure will result if any subsystem fails and that subsystems will fail if any element fails. This concept is useful in predicting the probability of equipment failure but it does not accurately represent an



R_{12000} = 0.031
R_{11000} = 0.057
Primary Treatment Subsystem
11000
R_{12100} = 0.156
Activated Sludge Secondary Treatment Subsystem
12100
R_{12200} = 0.241
Trickling Filter Secondary Treatment Subsystem
12200
R_{13000} = .002
Sludge Treatment and Disposal Subsystem
13000
R_{14000} = 0.940
Effluent Treatment Subsystem (Chlorination)
14000

CALCULATIONS:

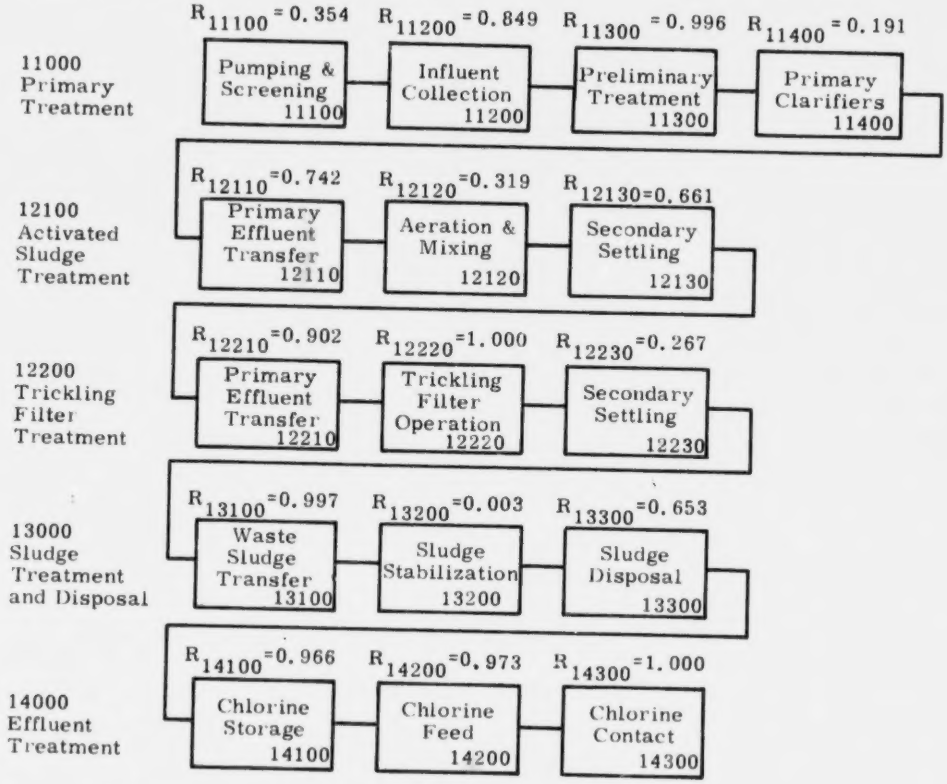
CALCULATIONS

The values of R were obtained using the formula $R = e^{-\lambda}$ where: λ = failure rate (failures per 1000 hr of operation) and t = 720 hours (one calendar month).

$$
\begin{aligned}
R_S &= R_{11000} \cdot R_{12000} \cdot R_{13000} \cdot R_{14000} \\
&= (0.057)(0.031)(0.002)(0.940) \\
&= 3.31 \times 10^{-6}
\end{aligned}
$$

Figure 15
System Level Reliability Model Block Diagram

SUBSYSTEMS


R11100 = 0.354
R11200 = 0.849
R11300 = 0.996
R11400 = 0.191
11000 Primary Treatment
Pumping & Screening 11100
Influent Collection 11200
Preliminary Treatment 11300
Primary Clarifiers 11400
R12110=0.742
R12120=0.319
R12130=0.661
12100 Activated Sludge Treatment
Primary Effluent Transfer 12110
Aeration & Mixing 12120
Secondary Settling 12130
R12210=0.902
R12220=1.000
R12230=0.267
12200 Trickling Filter Treatment
Primary Effluent Transfer 12210
Trickling Filter Operation 12220
Secondary Settling 12230
R13100=0.997
R13200=0.003
R13300=0.653
13000 Sludge Treatment and Disposal
Waste Sludge Transfer 13100
Sludge Stabilization 13200
Sludge Disposal 13300
R14100=0.966
R14200=0.973
R14300=1.000
14000 Effluent Treatment
Chlorine Storage 14100
Chlorine Feed 14200
Chlorine Contact 14300

CALCULATIONS:

$$R_{11000} = R_{11100} \cdot R_{11200} \cdot R_{11300} \cdot R_{11400}$$
$$= (0.354)(0.849)(0.996)(0.191) = 0.057$$

$$R_{12100} = R_{12110} \cdot R_{12120} \cdot R_{12130}$$
$$= (0.742)(0.319)(0.661) = 0.156$$

$$R_{12200} = R_{12210} \cdot R_{12220} \cdot R_{12230}$$
$$= (0.902)(1.000)(0.267) = 0.241$$

$$R_{13000} = R_{13100} \cdot R_{13200} \cdot R_{13300}$$
$$= (0.997)(0.003)(0.653) = 0.002$$

$$R_{14000} = R_{14100} \cdot R_{14200} \cdot R_{14300}$$
$$= (0.966)(0.934)(1.000) = 0.940$$

Figure 16
Reliability Model Subsystem Level Block Diagram

actual equipment/effluent relationship in a wastewater treatment plant. In biological treatment plants, there are "hidden redundancies" which cannot be easily identified or quantified. Many elements in the treatment plant can fail and remain out of order for a short time without adversely affecting effluent quality. For example, if the return sludge flow meters were inoperative, the operators could probably operate the plant for a few days on the basis of their experience and additional laboratory tests. This would be effective during that time, but not efficient. Another example would be failure of the primary scum removal equipment; a "certain amount" of floating solids could be accepted by the secondary system for a short time span. The amount of solids and the time duration allowable before adverse effects on the effluent are manifested are unknown. Thus, it can be concluded that the reliability model, as developed and demonstrated in this program, is only useful in predicting equipment failures. The state-of-the-art of biological treatment is not yet sufficiently advanced as to provide information for use in the models on the magnitude of effects on effluent quality and time dependency of an equipment failure. Because of the inherent variability in effluent quality due to other sources, as previously discussed, it is impossible to isolate the effects on effluent quality of most equipment failures except in extreme cases such as complete chlorinator breakdown or blower failure.

Maintainability Calculations

Maintainability calculations for MTTR are usually based upon averages of equipment maintenance repair times (R_e) derived from maintenance records, estimates by experienced personnel, timed observations, data tabulated for typical subtasks, or a combination of these sources. Perhaps the most practical derivation of R_e for waste treatment plant equipment is by the use of a combination of information from records and qualified estimates.

In a plant where records are kept of equipment failures, malfunctions and corrective maintenance man-hours, R_e, can be calculated using the following formula:

$$R_e = \frac{\text{Cumulative corrective maintenance man-hours during a given period}}{\begin{array}{c}\text{no. of failures +}\\ \text{no. of malfunctions}\end{array} \times \begin{array}{l}\text{average no. of men who normally}\\ \text{perform maintenance on the}\\ \text{equipment}\end{array}}$$

Example: Vacuum Filter-Filtrate Piping

Failure/malfunction mode--Piping blockage

$$R_e = \frac{8+5+10+7+4+6+9+11+12+8+17+12+5+4+7+3+9+4+8}{19 \times 2}$$

$$= \frac{149}{38}$$

$$= 3.92 \text{ hr}$$

Note that this number represents the mean time that is required to repair the equipment using a normal crew of two workmen.

Another practical method for determining R_e is to utilize experienced personnel to estimate the time required to perform basic repair subtasks which are: localization, disassembly, correction, reassembly and adjustment, and checkout. The following procedure would be used:

> Referring to failure and malfunction records and considering the most frequent failure mode, estimate the average localization time needed to determine that a problem exists and its location in the equipment.
>
> Referring to appropriate drawings, estimate the average disassembly time needed to gain access to the equipment problem area.
>
> Considering what must be done to eliminate the problem, estimate the correction time needed (including time to obtain tools, remove and transport an assembly to the shop, etc.).
>
> Referring to the drawings, estimate the time required to reassemble the equipment, including readjustments, as required.
>
> Referring to performance ratings for the equipment, estimate checkout time to assure that the equipment problem has been corrected.

This procedure enables the evaluation to include a breakdown of the total maintenance operation into smaller, more easily estimated segments.

To calculate the MTTR (mean time to repair) for the next highest level in the plant system (i.e. element level), the following formula can be used:

$$\text{MTTR} = \frac{\lambda_1 R_{e1} + \lambda_2 R_{e2} + \cdots\cdots \lambda_n R_{en}}{\lambda_1 + \lambda_2 + \cdots\cdots \lambda_n}$$

where: λ_1 = failure rate of equipment no. 1 in the element

R_{e1} = repair time of equipment no. 1 in the element

Example: Pumping and Screening Element

(Refer to Sheet 1, Appendix H, columns 1, 14, and 16)

$$\text{MTTR} = \frac{(.466\text{x}10^{-3})(5)+(.0004\text{x}10^{-3})(13)+(.228\text{x}10^{-3})(1)+(.228\text{x}10^{-3})(2)}{(.466\text{x}10^{-3}) \quad +(.0004\text{x}10^{-3}) \quad +(.228\text{x}10^{-3}) \quad +(.228\text{x}10^{-3})}$$

$$\frac{+(.007\text{x}10^{-3})(5.5)+(.114\text{x}10^{-3})(3)}{+(.007\text{x}10^{-3}) \quad +(.114\text{x}10^{-3})}$$

$$= \frac{(10^{-3})\ (.466\text{x}5)+(.0004\text{x}13)+(.228\text{x}1)+(.288\text{x}2)+(.007\text{x}5.5)+(.114\text{x}3)}{(10^{-3})(.466+.0004+.228+.228+.007+.114)}$$

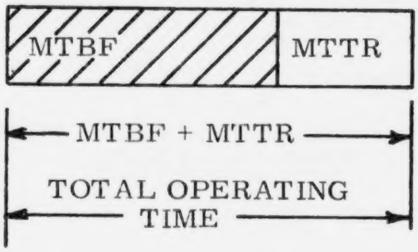
$$= \frac{2.33+.005+.228+.456+.038+.342}{1.043}$$

$$= \frac{3.399}{1.043} = 3.25 \text{ hr}$$

RELIABILITY AND MAINTAINABILITY RELATIONSHIPS

Availability

Probably the most commonly referred to reliability and maintainability relationship is availability (A). As defined earlier, availability is the ratio of reliability to reliability combined with maintainability. The diagram below illustrates the calculation of this ratio.



Example

Sewage pumps and motors availability is:

$$A = \frac{\text{MTBF}}{\text{MTBF + MTTR}} = \frac{8760}{8760 + 13} = 0.9986$$

This value is referred to as "inherent availability" because it is based upon the characteristics of the equipment and excludes "administrative" repair delays such as time awaiting delivery of a repair part. Values of availability for selected plant elements were obtained from Sheet 1 in Appendix H.

Maintenance Manpower Predictions

Probably the most valuable application of the reliability and maintainability relationship for wastewater treatment plants is the use of failure rate (λ), R_e, and MTTR for predicting corrective maintenance man-hour requirements. The calculations are very similar to that previously described for estimating MTTR.

To estimate corrective maintenance man-hours for an equipment item (M_c), the following formula can be used:

$$M_c = (\lambda_e + M_{ae}) \cdot (R_e) \cdot (P)$$

where:

λ_e = failure rate of equipment item (M_c)

M_{ae} = the reciprocal of MTBM (Mean Time Between Malfunctions)

P = no. of repairmen normally involved in a corrective maintenance task on the equipment

The calculated value M_c is the average number of hours spent in corrective maintenance per 1000 hours of system operation. The formula for predicting the number of hours to be spent on corrective maintenance during one 40-hour week (M_{cw}) would be:

$$M_{cw} = \frac{40}{1000} \times M_c$$

Example: Sewage Pumps and Motors

From the Data Summary Sheet (columns 7, 11, and 16) in Appendix H:

MTBM = 2920

$$M_{ae} = \frac{1}{2920} \times \frac{1000}{1000} = 0.342 \times 10^{-3}$$

$$\lambda_e = 0.114 \times 10^{-3}$$

M_c = $(0.114 + 0.342)(10^{-3})$ failures and malfunctions per 1000 system operating hours (13 avg. hr per repair)$\cdot$(1 man)

$= \frac{0.456 \times 13}{1000}$ = 5.934 Corrective maintenance man-hours per 1000 system operating hours

$$M_{cw} = \frac{40}{1000} \times 5.934 = 0.237 \text{ Corrective maintenance man-hours per 40 hr work week}$$

The amount of corrective maintenance which can be expected during, say, a 40-hour work week would be added to an estimate of additional maintenance (i.e., preventive maintenance recommended by the equipment manufacturer) to arrive at an estimate of total maintenance required during the 40-hour week. No doubt the calculated estimate for corrective maintenance would influence planning for additional preventive maintenance to prevent, to the greatest reasonable degree, failures and malfunctions from occurring.

To estimate preventive maintenance man-hours for an equipment item, the following formula can be used:

$$M_p = (f_e)(P_e)$$

where: f_e = frequency of preventive maintenance recommended by the equipment manufacturer minus maintenance which is recognizable as duplicating corrective maintenance previously considered.

P_e = average preventive maintenance man-hours determined by an analysis of recommended tasks similar to that performed in estimating corrective maintenance man-hours. (i.e., localization time estimate, disassembly time estimate, etc.)

Example: Sewage Pumps and Motors

Manufacturer's recommended preventive maintenance which is in addition to identified corrective maintenance actions

$$= \frac{2 \text{ actions}}{3 \text{ months}}$$

$$f_e = \frac{2 \text{ actions}}{3 \text{ months}} \times \frac{1 \text{ month}}{4 \text{ weeks}} = \frac{2}{12} \frac{\text{actions}}{\text{week}} = 0.166 \frac{\text{actions}}{\text{week}}$$

Assuming an average value (which would be obtained from an analysis of the times required to perform the preventive maintenance tasks) of 2.5 hr for P_e:

$$M_p = (0.166)(2.5) = 0.415 \text{ hr per week}$$

The total estimated maintenance requirement for sewage pumps and motors would then be the sum of the preventive and corrective actions as shown on the next page.

$$M_t = M_p + M_c$$

$$= 0.415 + 0.237 = 0.652 \text{ hr per week}$$

Of this total, preventive maintenance would represent about 63.7 percent of the total effort. If, from this analysis, it was found that the CM/PM split was reversed, additional PM should be scheduled to reduce CM requirements.

PLANT EVALUATION

To exhibit the utilization of reliability and maintainability evaluation techniques previously described in this section, a case problem has been developed for determining subsystems, elements, and equipment which degrade system performance. Failure Modes and Effects Analysis (FMEA) is included in this approach used for determining a solution to an equipment reliability problem.

Reliability, Maintainability, and Availability Assessments

Various methods can be used in selecting and evaluating a specific equipment for detailed reliability, maintainability, and availability characteristics analysis. A method which is considered to be logical and effective is summarized in Figure 17 and illustrated in succeeding paragraphs using examples from the Flint plant.

The most serious equipment failures are those which affect the successful operation of the entire plant. These failures can be identified by "inserting" failures into a reliability block diagram prepared for the plant and assessing their effect on the plant.

Using this method, it was determined that during the one-year data reporting period there were no equipment problems which resulted in a total failure of the plant process. The reliability block diagrams were then examined to determine if a failure or a combination of failures could have occurred at the same period of time which would have hypothetically resulted in a total plant failure.

Examination of the plant's "Equipment Malfunctions" reports show that during the period November 11-12, 1970, five equipment failures occurred. These failures, added to one which was still uncorrected from November 10, totaled six equipment failures and represent the largest number of concurrent failures experienced by the plant during the reporting period.

1. Select specific equipment for evaluation

   (a) Identify the equipment items which are causing the most serious problems in the plant.

   (b) Review plant and equipment reliability and maintainability information.

   (c) List problem equipment in descending order of importance to plant operation.

2. Examine equipment problem facts

   (a) Organize factual information and make an assessment of the effect of each problem on plant operation.

   (b) Examine and interrelate reliability and maintainability information to determine failure modes, frequencies, and their impact on plant operation and maintenance.

3. Generate (innovate) and evaluate different ways to solve each problem

   (a) Consider various alternatives so the best way to solve an equipment problem will not be overlooked.

   (b) Consider various actions which can be taken.

   (c) Evaluate and select the best practical solution to each problem.

   Examples:

   (1) Perform preventive maintenance prior to the anticipated time of failure.

   (2) Add redundant equipment to take over operation while the other unit is being repaired.

   (3) Improve reliability of the function by replacing existing equipment with a more reliable or stronger unit.

   (4) Improve reliability of existing equipment by modifying the design.

   (5) Decrease repair time by equipment or procedure modification.

4. Develop a course of action to be taken.

   Describe the best actions which must be taken to bring a problem under control.

Figure 17

Recommended Reliability and Maintainability Analysis Method

	Failure Condition	Effect on Plant Process
1.	No. 5 primary clarifier sludge control valve inoperative.	Slight buildup of sludge in tank until valve repaired on 11/12/70
2.	No. 3 primary clarifier sludge pump packing seal leaking excessively.	Slight buildup of sludge in tank until pump repaired on 11/13/70
3.	No. 1 blower overheating bearing.	Standby (No. 2) blower placed in operation until No. 1 repaired on 11/12/70
4&5.	No. 2 and No. 3 sludge pumps in incinerator building inoperative.	No. 1 sludge pump used until repairs on Nos. 2 & 3 completed on 11/12/70
6.	No. 4 primary clarifier scraper and cross collector chain drive inoperative.	Slight scum and sludge accumulation in tank until repair completed 11/13/70

The combination of these six failures did not result in a failure of the plant process.

The second most serious equipment failures are those which most degrade plant subsystems and thereby threaten the successful operation of the entire plant. These failures are identified by examining the reliability models from the top (plant level) down (to the equipment level).

Referring to Figures 15 and 16 it can be seen that Sludge Treatment and Disposal is the least reliable subsystem (0.002) and that Sludge Stabilization is the element (0.003) causing the largest part of the problem. The reliability value calculated for this element is due primarily to the relatively large number of equipment items which comprise the element. That is to say that the reliability, which is the product of multiplied decimal fractions, is inversely proportional to the quantity of the number being multiplied. The low reliability of the Sludge Stabilization element of 0.003 is caused primarily by the low reliability of the Air Flotation Thickener at 0.101 and the low reliability of the Chemical conditioning Equipment at 0.286. Further evaluation showed that within these groups the Thickened Sludge Meter (0.478), Grit Scraper Mechanism and Controls (0.518) and Lime Feeding Mechanism (0.730) were the equipment items which were the least reliable. Improving the reliability of this equipment would improve the overall reliability of the plant and reduce corrective maintenance costs. Although these items are fundamental to the overall plant process, they perform a function which is not absolutely essential to successful treatment. Further investigation of these items might be deferred until equipment with low reliability, which is essential to the production of an acceptable effluent, is evaluated and remedied. Essential equipment with low reliability is regarded as critical to the plant process until effective remedial action has been taken to raise its reliability to an acceptable level.

"Activated Sludge" Secondary Treatment is the essential subsystem having the next lowest reliability to Sludge Treatment and Disposal and therefore is relatively critical compared to the other subsystems in the plant. In performing a similar analysis of the Activated Sludge Subsystem, which has a lower reliability value than the Trickling Filter Subsystem, it was determined that the Return Sludge Meters (0.373) and the Settled Sewage to Aeration Tank Meters (0.440) have the lowest reliability and greatest effect on subsystem reliability. The "tracing sequence" diagram, used for synthesizing information in the models and calculation sheets to arrive at these equipment items, is illustrated in Figure 18. Although both of these meters perform an essential control function relative to treatment of what will become plant effluent, the function performed by the Return Sludge Meter is duplicated by another meter and is located in the plant's meter room. This is not the case with the Settled Sewage to Aeration Tank Meters; therefore, without function preservation provided by a standby, they are considered the more critical.

The function performed by these meters is to indicate the instantaneous flow rate of settled sewage (from the primary clarifiers) going to each aeration tank. A failure of one of these meters deprives the plant operator of knowing whether the actual return sludge flow rate corresponds to the rate set by the operator. Although failure of this meter would signal an immediate system failure, the operators could probably "get by" for several hours by determining the approximate flow from the valve setting.

Failure Modes and Effects Analysis

Failure Modes and Effects Analysis (FMEA) provides a systematic procedure for continuing detailed evaluation by using a format for identifying and assessing the likelihood, consequences, and corrective action which should be taken for significant modes of a failure. An example using this format for guiding the analysis is shown in Figure 19.

The type of information used to develop corrective action descriptions contained in the FMEA format is illustrated in the simple table and time plot below for the Aeration Tank Meters. They provide an additional insight into the nature of the failure problem, showing that the meters failed approximately every three weeks or multiples thereof.

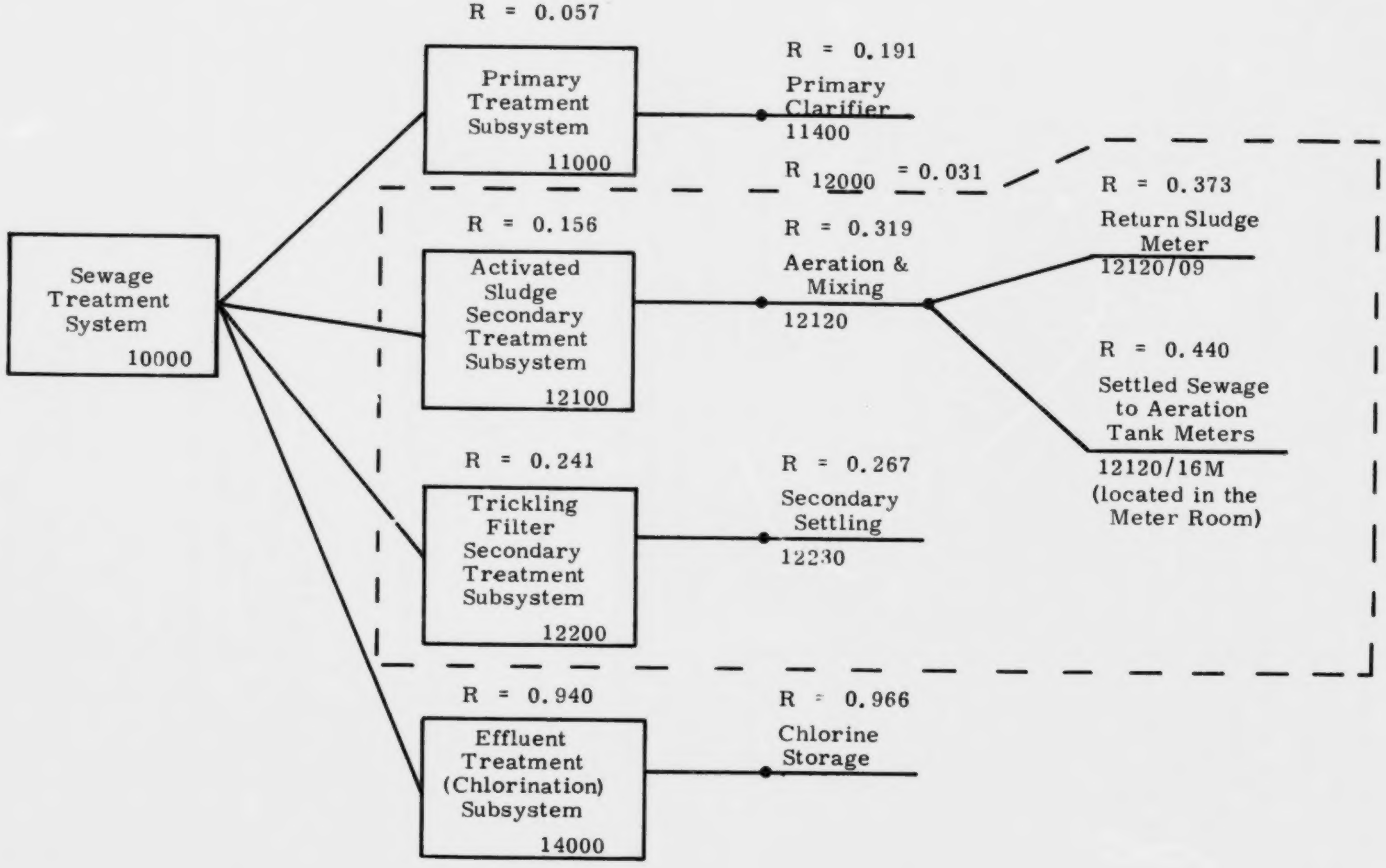

Sewage Treatment System 10000
R = 0.057
Primary Treatment Subsystem 11000
R = 0.191
Primary Clarifier 11400
R 12000 = 0.031
R = 0.156
Activated Sludge Secondary Treatment Subsystem 12100
R = 0.319
Aeration & Mixing 12120
R = 0.373
Return Sludge Meter 12120/09
R = 0.440
Settled Sewage to Aeration Tank Meters 12120/16M (located in the Meter Room)
R = 0.241
Trickling Filter Secondary Treatment Subsystem 12200
R = 0.267
Secondary Settling 12230
R = 0.940
Effluent Treatment (Chlorination) Subsystem 14000
R = 0.966
Chlorine Storage

Figure 18

Identification of Low Reliability Items

Subsystem (1) 12100 Activated Sludge Secondary Treatment
Element (2) 12120 Aeration and Mixing

Equipment Identification			Failure Modes and Effects Assessment							Solution
				Effects on						
Equipment (3)	Function (4)	Equip. Relative Failure Freq. (5)	Failure Mode (6)	Equipment (7)	Element (8)	Mode Proba-bility in Equip. (9)	Mode Proba-bility in Elem. (10)	Safe-ty (11)	Cause of Failure (12)	Correct Action Recommended (13)
12120/16M Settled Sewage to Aeration Tank Meter	Indicate (in MGD) settled sewage flow rate to each aeration tank	System 0.033 (10/302) Sub-system 0.182 (10/55)	A) Stuck at one meter reading	Meter fails to indicate flow rate of settled sewage to an aeration tank	Inappropriate amount of sewage sent to aeration tank	0.40 (4/10)	0.095 (4/42)	II	Amplifier failure	A) Perform PM every 21 days. B) Report failures to amplifier manufacturer
			B) Indicating needle oscil-lates	Same as above	Same as above	0.40 (4/10)	0.095 (4/42)	II	Amplifier failure	A) Perform PM every 21 days. B) Report failures to amplifier manufacturer
			C) Indicating incorrect value	Same as above	Same as above	0.20 (2/10)	0.0475 (2/42)	II	Amplifier failure	A) Perform PM every 21 days. B) Report failures to amplifier manufacturer

Figure 19

Failure Modes and Effects Analysis

Sheet 1 of 2

Description of the Contents of a Failure Modes and Effects Analysis Worksheet

1. Subsystem identification code number and nomenclature
2. Element identification code number and nomenclature
3. Equipment identification code number and nomenclature
4. Description of the function performed by the equipment
5. Equipment relative failure frequency in the system and subsystem
   Rel. fail. freq. (sys.) = no. of equipment failures/no. of system failures
   Rel. fail. freq. (sys.) - no. of equipment failures/no. of subsystem failures
6. Description of failures obtained from malfunction log
7. Effect of failure on equipment
8. Effect of failure on element
9. Probablity of failure mode occurring in the equipment

$$\text{Prob. of mode in equipment} = \frac{\text{no. of failures (in mode)}}{\text{no. of equipment failures}}$$

10. Probability of failure mode occurring in element

$$\text{Probability of mode in equipment} = \frac{\text{no. of failures (in mode)}}{\text{no. of element failures}}$$

11. Safety hazard class using the following definitions:

Class I SAFE--Conditions such that personnel error, deficiency/inadequacy of design, or component malfunction will not result in major system degradation and will not produce system functional damage or personnel injury.

Class II MARGINAL--Conditions such that personnel error, deficiency/inadequacy of design, or component malfunction will degrade system performance but which can be counteracted or controlled without major damage or any injury to personnel.

Class III CRITICAL--Conditions such that personnel error, deficiency/inadequacy of design, or component malfunction will degrade system performance by personnel injury or substantial damage or will result in a hazard requiring immediate corrective action for personnel or system survival.

Class IV CATASTROPHIC--Conditions such that personnel error, deficiency/inadequacy of design, or component malfunction will severely degrade system performance and cause subsequent system loss or death or multiple injuries to personnel.

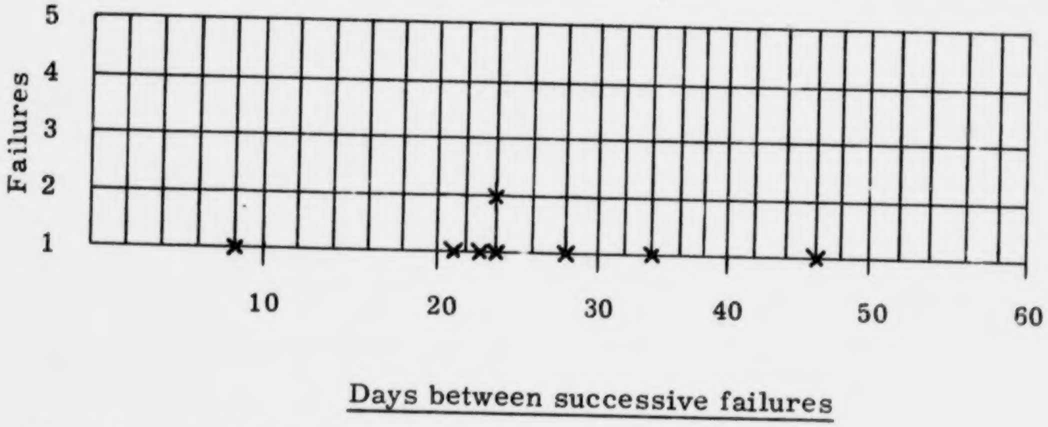
12. Description of the cause or probable cause of failure
13. Corrective action alternative

Figure 19

Failure Modes and Effects Analysis
(Continued)

Sheet 2 of 2

Intervals between failures	Days elapsed between failures
1-2	24
2-3	23
3-4	46 (or, 2 x 23)
4-5	82 (approx. 4 x 21)
5-6	24
6-7	8 (or, 1/3 x 24)
7-8	21
8-9	28
9-10	34



Based upon this analysis, if successful preventive maintenance on meter amplifiers is performed every three weeks, meter failures could be reduced as much as 80 percent. Reducing the number of failures in the meter by this amount would increase its reliability 93 percent from 0.440 to 0.849 and decrease failures in the aeration and mixing element by 16 percent.

In addition to increasing preventive maintenance on these meters, the manufacturer should be advised of the performance of his product in the plant. In many cases, this is not done and an equipment problem can persist for years without the knowledge of the manufacturer. This type of information is particularly vital to the manufacturer who is trying to improve the reliability and maintainability of his product.

DISCUSSION

From the foregoing presentation on the application of R&M techniques to the Flint Sewage Treatment Plant, certain conclusions and recommendations can be drawn in respect to general use. These have been categorized into three major areas (equipment reliability, system reliability, and manpower planning) and are discussed in the following paragraphs.

Equipment Reliability

Little data are available on the reliability characteristics of wastewater treatment equipment. Except for very large installations, few plants keep records which indicate the frequency and severity of equipment failures. Reliability information, such as it is, normally is distributed by word-of-mouth. Consequently, it is based more on opinion than on hard data. Nevertheless, reliability reputations are built and destroyed by this informal communications technique. As a result, there is a natural tendency on the part of designers to be very conservative in their choice of equipment; since little or no data are available, designers will choose equipment that has some demonstrated performance characteristics. Due to the informal communication process, the development of confidence in the reliability of a given equipment item can only take place over a long time period. Consequently, there is a tendency to avoid new approaches in equipment design. This has been a strong criticism of the wastewater treatment profession. The techniques of R&M data collection discussed in this section and illustrated in Appendices G and H could be applied in other plants with minimum additional effort. Equipment malfunctions, failures, etc., are easily recorded, as is the practice at Flint. The index system developed by the System/Equipment Staging Diagrams is most helpful in organizing the data for easy reference. From this beginning, only simple mathematics are required to calculate MTBF or MTBM for equipment. If warranted, these calculations could be programmed for computer analysis along with suitable reporting forms for management control.

The collection and organization of these data could form a basis for the development of performance ratings for wastewater treatment equipment. This would provide plant designers with equipment performance data which are not currently available. At the same time, it would motivate manufacturers to improve their products, particularly with respect to the specific problems being experienced in the plants. It would provide a state-of-the-art baseline of equipment performance. The same information could also be used as minimum performance goals for manufacturers of new equipment. If new equipment could be rigorously demonstrated to have equal or superior performance and reliability characteristics in comparison to existing equipment, the reluctance of plant designers to specify new technology will be diminished.

System Reliability

One goal of this program was to assess the applicability of reliability models to: (1) describe the effect of equipment failures on overall system performance in terms of effluent quality, and (2) depict the reliability relationships between equipment, elements, subsystems, etc. It was found that the reliability model approach could not correlate equipment failure with effluent quality deterioration. Primarily, this is due to the current lack of knowledge of the dynamic relationships between wastewater characteristics and equipment capabilities and performance. For example, one cannot qualitatively assess the effect of failure of the grit removal system over certain time spans (five minutes, one hour, one day, one year). Thus, the state-of-the-art of biological wastewater treatment is not sufficiently advanced to allow the model to represent equipment-effluent quality relationships. This problem is similar to that discussed in Section VIII on Quality Control. Until a better understanding of the biological process is reached, it will not be possible, in most cases, to determine whether the cause of variation in effluent quality is due to raw waste characteristics, design deficiencies, operator error, or equipment failure. Thus, it is again recommended that studies be performed to increase our knowledge of the real performance of biological waste treatment plants.

In this program, a reliability model showing the reliability relationships between equipment, subsystems, elements, etc., was prepared. This model was demonstrated to be of value for analyzing the probability of equipment failures and malfunctions throughout the plant. The technique is useful for evaluating the magnitude of an equipment problem in relation to the total plant equipment and can also be used to determine the degree of improvement which would result from corrective action.

Manpower Planning

In Section VII, staffing analysis techniques were presented for operating and preventive maintenance functions based upon the development of OSD's and Function-Capability-Equipment Matrices and Operational/Maintenance Task Matrices. In this section, techniques for developing staffing estimates for unscheduled (or corrective) maintenance were demonstrated. While a rigorous staffing procedure cannot be developed because of the random nature of CM requirements, the maintainability calculations, based upon MTBF and MTTR values provide an excellent guide for the provision of CM services. A procedure was demonstrated for estimating the CM man-hours per week for a given equipment group, based upon past experience. If PM efforts and requirements have been documented, plant management can then make rational decisions as to the advisability of increasing PM or modifying equipment in order to reduce downtime or CM requirements due to failures. Thus, a tool is provided by which corrective maintenance can be controlled to a much higher degree than is currently the case.

SECTION X

APPLICABILITY OF INDUSTRIAL ENGINEERING TECHNIQUES TO ADVANCED WASTE TREATMENT

BACKGROUND

Over the past decade, it has become apparent that in many instances effluent quality higher than that normally associated with secondary treatment will be required to protect critical water resources. To meet this challenge, a wide variety of unit operations have been and are being developed; these processes are normally described as "advance waste treatment" (AWT). Secondary treatment is almost exclusively concerned with the removal of BOD and suspended solids. While higher removal levels of these constituents may be required, other considerations, such as removal of phosphates, nitrogen, or dissolved materials, may be significant in relation to a particular receiving stream. Thus, the term "advanced waste treatment" may be applied to a large number of processes which either improve on secondary treatment performance or remove or alter other constituents. The most commonly discussed AWT processess include:

- Phosphate Precipitation (lime and/or alum addition)
- Carbon Adsorption
- Microstraining
- Pressure Sand Filtration
- Rapid Sand Filtration
- Ammonia Stripping
- Breakpoint Chlorination
- Biological Denitrification
- Ion Exchange
- Electrodialysis (ED)
- Reverse Osmosis (RO)
- Distillation

These processes are widely described in the literature; an overall discussion can be found in Reference 13. With the exception of biological nitrification-denitrification, all of the above processes rely on chemical and/or physical processes. While these processes are relatively new to the wastewater field, it should be noted that several have been used for many decades in water supply treatment: lime or alum clarification, filtration, breakpoint chlorination, and stripping. Microstraining has been extensively applied to water treatment; ED, RO, ion exchange, and distillation have been applied to desalting brackish or sea water.

While some questions are arising regarding the ability to remove trace refractory materials, the traditional water treatment processes have enjoyed a much higher reputation of being able to consistently produce an acceptable effluent in comparison to wastewater treatment plants. There are, of course, several reasons for this difference in performance, not the least of which is the difference in raw materials.

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A major difference in operating requirements between water and wastewater treatment systems is in the variability of the influent characteristics. Flow rates to water treatment plants are, as a rule, kept nearly constant; clarifier and filter efficiencies are directly dependent upon clarifier overflow and filter application rates. Also, raw water characteristics do not vary as widely as sewage. There are basic differences in the operating modes between the biological and physical/chemical processes that also help explain the difference in performance. As discussed in previous sections, upsets in the biological process are both difficult to determine on-line and to control. In filtration or adsorption systems, an upstream malfunction resulting in, for example, increased suspended solids or dissolved carbon content will usually only shorten the operating cycle (backwash or carbon regeneration). Thus, upset would result in increased operating inputs such as backwash water, operator time, etc. Another major difference is in waste solids handling. A large portion of the maintenance problems in wastewater treatment is related to sludge handling and disposal; it is only recently that consideration is being given to treatment of water plant sludges.

The analogy of AWT processes to industrial activities is equally as valid as that for secondary wastewater treatment. An evaluation of the applicability of industrial engineering techniques to AWT was performed to determine significant differences, if any, in comparison to that associated with secondary treatment. This evaluation was based upon a review of AWT process technology and a visit to the South Lake Tahoe AWT Plant,which is the largest and most experienced AWT installation in the United States.

The Lake Tahoe plant includes a conventional secondary biological treatment plant followed in series by lime precipitation and settling, air stripping, multimedia separation beds, carbon adsorption, and chlorination. The treated effluent is pumped to Indian Creek Reservoir, a man-made lake, which is used for swimming, boating, fishing, and as a source of irrigation water. Detailed descriptions of the unit operations can be found in Reference 13.

DESIGN AND OPERATION

In Section V, techniques were demonstrated for developing preliminary designs and operating procedures by identifying and systematically satisfying required functions. This approach involved the use of Functional Staging Diagrams, System/Equipment Staging Diagrams, Function-Capability-Equipment Matrices, Correlation Matrices, Adjacency Charts, and Operation Sequence Diagrams. All of these techniques were found applicable from the standpoint that they would provide a rational means of organizing decision-making and developing operating plans.

While there are variations in secondary biological treatment, the basic process elements are the same: contact wastes with microorganism and separate microorganisms from treated wastes to remove BOD and suspended solids. For AWT there are many more optional approaches, not only in the constituents to be removed (BOD, suspended solids, phosphorus, nitrogen, dissolved organics, and dissolved inorganics), but also in how it is removed. For example, nitrogen can be removed by biological nitrification-denitrification, air stripping, selective ion exchange, or breakpoint chlorination, all of which are quite different in their removal mechanisms. The FSD's developed must, therefore, be more general than those associated with secondary treatment. Appendix M contains a sample FSD sheet for removing dissolved inorganic material. Other FSD's were prepared for: removing or altering nutrient materials; removing suspended solids; and removing residual dissolved organic matter.

System Equipment Staging Diagrams and Function-Capability-Equipment Matrices would be prepared in the same manner as discussed in Chapter V. Their utility as checklists is heightened since "universal" design criteria have not been developed for AWT. Thus, it would be very beneficial for the designer and design reviewer to have the capabilities and matching equipment selections displayed for ready reference.

Where AWT is being considered, the quality of the effluent will be required to be consistently high. Consequently, provisions must be made for dealing with off-quality effluent or various failure modes. Layout of the plant assumes greater importance than in convential plants since recycle of off-quality effluent could be handled in a number of ways. The Lake Tahoe plant contains two ballast ponds which serve several functions: (1) store ammonia stripping effluent for use in backwashing the separation beds; (2) equalize peak flows so that the separation beds and the carbon adsorption column can operate at a steady rate; (3) provide settling for turbid decanted backwash water if required; and (4) storage for inadequately treated wastes before recycle to the separation beds. The ponds can receive wastes which have passed the lime clarification and/or the NH_3 stripping tower. Thus, the ballast ponds must be located in close proximity to a number of unit operations. The Correlation Matrix and the Adjacency Chartare quite useful in developing a facility layout for these conditions.

Operational aspects of AWT may be significantly different than those associated with secondary treatment. At Lake Tahoe, for example, operators of the AWT Plant must make decisions as to separation bed backwash, carbon regeneration, and lime feed rate, all of which have a direct effect on effluent quality. Thus, it is very important that standard operating procedures or guidelines be developed to ensure that operating decisions and practices are correct and the operator's time is efficiently utilized. In this regard, the OSD technique is quite useful for delineating the detailed tasks that must be performed by individual operators.

The Lake Tahoe plant has an operations manual considered by many to be a model for a complete reference document. Over 80 illustrations are included, most of which provide detailed data on process configurations under a variety of operating modes. For example, piping and valving diagrams are given for operating the carbon columns in the following configurations: (1) normal upflow operation; (2) upflow to waste; (3) reverse flow; and (4) bypass. A complete outline of this manual is given in Reference 13. The manual does not, however, relate man and machine. While certain procedures and operating criteria are given for numerous contingencies, actions of the operator himself, under normal and nonroutine conditions, are not outlined. As stated earlier, these operator routines are usually developed in an informal fashion and are passed on by "in-service training" to new personnel. The development of standard operating procedures would allow review of operator performance and would provide an effective training aid.

MAINTENANCE

The development of an effective maintenance management plan, as discussed in Chapter VI, can be accomplished by developing an equipment list from the Function-Capability-Equipment Matrices followed by maintenance procedure evaluation and the preparation of Maintenance Procedure Cards (MPC). Most AWT processes require conventional equipment regularly used in chemical processing and in wastewater treatment (pumps, tanks, filters, etc.); therefore, the above approach could be used to the same advantage for AWT processes as is realized in the chemical industry.

The Lake Tahoe plant has developed a maintenance program which includes some of the above management elements. A preventive maintenance equipment list has been prepared which is indexed by area (blower room, digester area, tertiary plant, etc.). This list contains almost 450 equipment entries related to the treatment processes. Of this total, about half are associated with AWT processes. Preventive maintenance management is based upon an Inspection and Service Record Card System which is indexed according to the PM equipment list. Each item of equipment requiring PM is listed on a separate card. The card describes the work to be done and the frequency. Detailed maintenance procedures are not provided on the card. A sample Inspection and Service Record Card is given in Appendix J.

Maintenance at the Lake Tahoe plant is performed by four separate groups. Almost all PM is performed by the operators. The shift foreman removes the applicable cards from a master file according to a required schedule (daily, weekly, etc.), and assigns the PM work to specific operators. The regular maintenance crew is authorized to consist of a maintenance supervisor, two mechanics, one electrician, an equipment repairman (who is also involved with maintenance of automotive equipment), and two utility men. The crew spends about 90 percent of their time on Corrective Maintenance. Their work generally requires higher maintenance skills than the PM performed by the operators. The sewer cleaning crew occasionally performs light maintenance functions, such as cleaning out clarifiers, the barminutor, etc. An outside contractor performs PM services on all pneumatic and electrical equipment (meters, sensing units, thermocouples, panel boards, timers, etc.). They also furnish the required replacement parts.

During the day, the operating crew usually consists of seven men, including the chief operator. The two night shifts normally consist of four men. During these hours one man is in the lab and the other two are doing PM and inspections. On the day shift, the extra two men are used in the lab doing PM or general tasks that are best done during the day. It is interesting to note that the plant attracts so many visitors that one man spends a significant amount of time leading tours.

No data on the overall distribution of maintenance between PM and CM were available. However, one can derive a rough estimate on the assumption that 90 percent of the maintenance crew effort is CM and two operators per shift are on PM. On this basis about half of the effort is PM. However, when the outside contractor and the sewer crew PM functions are added, it can be concluded that the PM effort is significantly greater than half of the total maintenance effort.

An informal assesment by plant management indicated that the major maintenance problem areas were: centrifuge gear heads and scrolls, grit removal equipment, digester cleaning, primary sludge pump, lime slakers, and stripping tower scale. All except the last item are associated with conventional treatment. Stripping tower scale is thought to be a design problem which could be avoided or minimized in subsequent installations.

It must be noted that while the Lake Tahoe plant is designed for 7.5 MGD, it has been operating at about half that rate. Many of the components of the plant are provided as multiple units. Since the plant has been underloaded, standby equipment, which would be required at full capacity, is available in addition to the designed redundant elements for use in the event of equipment failure.

STAFFING

As discussed in Section VII, the development of a staffing level for a conventional plant is normally based upon available data from past experience. For AWT plants, this approach is not valid since very few processes have been closely duplicated at other installations. Thus, staffing for AWT plants must be developed from consideration of the tasks that must be performed.

Using FSD's, ESD's, an equipment list, and the Operation/Maintenance Task Matrices, the designer or manager can develop an excellent staffing rationale. At the same time, the groundwork is laid for standard operating procedures for operators.

QUALITY CONTROL

Substantial investment is required for AWT facilities; this investment is presumably made because lesser quality effluent is not acceptable. Because of the higher investment and quality goals, quality control is more important for AWT plants than for conventional installations.

The criteria for effective quality control programs, as practiced in industry, are the same for AWT as for secondary treatment. These are: statement of product quality goals; ability to control processes; effective quality measurement techniques; and effective feedback communications.

The clear statement of quality goals and an effective information feedback system are dependent upon the policies of the regulatory agencies and the plants involved.

The Lake Tahoe plant offers an interesting example of the variation in settling process goals. The South Tahoe Public Utility District was ordered by the Governor to export treated wastes from the Lake Tahoe watershed. The Public Utility District was able to negotiate an agreement with the Lahontan Regional Water Quality Control Board, a state board, for discharge to an area in Alpine County, provided the effluent met certain quality characteristics. At that time, Alpine County passed a series of ordinances which fixed the allowable point of discharge and established separate effluent standards. The Alpine County regulations are of the "not to exceed" type while the Lahontan RWQCB requirements are based upon a frequency distribution. A monthly summary sheet giving both requirements and performance is in Appendix J.

The ability to control the process depends upon the AWT process considered. If, for example, the effluent from carbon adsorption towers is too high in dissolved organics, the operator has the option of regenerating the carbon or decreasing the application rate providing he has standby columns or storage facilities. Process controls for ammonia removal by air stripping are less effective. As the ambient temperature drops, removal efficiency declines. For a fixed air blower capacity, there is essentially nothing the operator can do to remedy this situation. The biological nitrogen removal systems suffer the same problems as conventional secondary treatment: the kinetics of the processes are not well enough understood to control the variations of the effluent quality. Filtration processes can be "controlled" by backwashing or alteration of application rate. Polyelectrolytes are sometimes added to overcome deficiencies in upstream gross solids removal. In most cases, the chemical oriented techniques are easily controlled by adjusting feed rate. Thus, for most of the chemical/physical type AWT processes, control can be exerted by increasing or decreasing an operating input such as: backwash frequency; regeneration frequency; filter or carbon column application rates; and chemical feed rates.

The ability to control processes is dependent upon the availability of effective measurement techniques. The difficulties associated with the BOD and suspended solids tests as indications of quality and as process control parameters, as previously discussed, are primarily due to the inability to measure the parameters of interest directly (MLSS) as well as the duration of the BOD test. Most of the AWT processes are concerned with measuring materials which are readily measured: PO_4, NH_3, turbidity, total or organic carbon. For these constituents, the analyses are rapid, direct, and, in many cases, can be continuously monitored. For process control purposes, the operator can then have a continuous record of process performance. If effluent quality is slowly degrading, he can take operating measures, such as backwashing or regeneration, before the degradation becomes critical. Recording on-line instruments can also provide a history which can be used to evaluate not only overall process performance, but also the effects of equipment or operator failure and knowledge of process characteristics.

RELIABILITY AND MAINTAINABILITY

The R&M approach considered in Section IX was evaluated for two basic purposes: (1) determine the probability of equipment failure and the means for minimizing effects; (2) determine the probability that the effluent would not meet stated product goals due to equipment failure. It was concluded that R&M calculations could be quite beneficial in reaching the first objective but that the state-of-the-art of biological treatment was not sufficiently advanced to use R&M analyses to reach the second. The utility of R&M analysis toward control of AWT equipment failure is equal to that for secondary treatment. The results and conclusions generated in Section IX in regard to this approach hold for AWT processes.

As technology develops, the effluent from the AWT plants will be routed to higher uses. The Lake Tahoe effluent goes to a reservoir which is used for fishing, boating, swimming, and irrigation. At Windhoek, South Africa, the AWT effluent is blended into the raw drinking water supply. As the quality requirements for AWT effluent become higher, the reliability of the AWT treatment processes will become more critical. South Tahoe, in addition to its ballast ponds, has a 60 MG storage reservoir which can be used to hold substandard effluent for return to the treatment plant. Obviously, facilities of this type are expensive. The development of techniques to assess the probability of the frequency and duration of plant failures would be valuable in evaluating the relative cost and benefits derived from such facilities. Many of the physical and chemical unit processes are more amenable to the modeling approach discussed in in Section IX as applied to the prediction of failure to meet quality goals than are secondary treatment processes. For example, if a secondary clarifier sludge pump fails, a certain unknown time span will elapse before the effluent quality begins to deteriorate; if the stripping tower blower motor fails, ammonia removal will cease. Also, variations in the influent quality to most AWT processes are met by increasing or decreasing "operating inputs" (backwash, etc.). On the other hand, little is known about the response of the activated sludge system to constantly varying BOD and hydraulic loadings.

It should be possible to develop an R&M model for a specific train of AWT processes, such as at Lake Tahoe, to correlate equipment failure with product quality. Separate submodels could be developed for the various constituents of interest. In each case, the relationship between equipment and quality would change since each unit operation is intended to remove different constituents; however, some are capable of removing other constituents, if required. For example, the carbon columns could act as a filter in the event of a failure in the separation bed which resulted in a high suspended solids feed to the carbon columns.

DISCUSSION

There is no question that AWT processes will be increasingly employed in the near future. Because of the high costs involved and the desire to produce a consistently high quality effluent, the industrial engineering techniques described and evaluated in earlier sections for secondary biological treatment systems are not only applicable but also highly desirable.

Design and operation practices for secondary plants have evolved empirically over a period of several decades. Past experience is available to designers and plant managers as a basis for building or operating plants, regardless of the inefficiency or inadequacies of this approach. For most AWT processes, this information is not yet available. A procedure for organizing the development of design and operating practices would be quite beneficial.

The recommendations given in Chapters V through IX that deal with industrial engineering techniques are equally applicable to AWT processes. In addition, however, it is recommended that a Reliability Model be prepared for an AWT plant, such as Lake Tahoe, with the goal of correlating equipment failure to effluent quality. The development of this model would provide guidelines for application of R&M analysis for other AWT plants.

SECTION XI

SUMMARY DISCUSSION

Over the past decade, billions of dollars have been spent in the construction and treatment facilities for the purpose of upgrading the quality of our water resources. The success of these facilities in meeting desired goals, however, is highly dependent upon the operation and maintenance policies employed. Operating policies for conventional treatment facilities have evolved through the years by trial-and-error and have been strongly influenced by the incentives and priorities set by society. With today's increasing concern, not only for the protection of the environment but also for protecting the growing investment in treatment facilities, interest is turning to methods by which the performance of conventional plants can be improved. Over the past few decades, techniques have been developed to better control and manage the operation of complex systems. Among these techniques, Work Study and Reliability and Maintainability Analysis have enjoyed considerable success, particularly in military systems. The purpose of this program was to evaluate the applicability of these techniques as well as selected other industrial engineering techniques to the operation and maintenance of wastewater treatment plants. This was done by applying the techniques to an existing plant as a case study and by consideration of current priorities in the waste treatment field. For evaluative purposes, conventional secondary treatment was considered analagous to an industrial manufacturing facility. Consideration was also given to the applicability of the techniques studied to advanced waste treatment processes.

At the outset of the program, initial efforts were directed toward the application of individual techniques to specific problems. As the program progressed, however, it became apparent from consideration of industrial practices, the overall management of waste treatment plants is generally poor in comparison to industries with comparable capital investments. Thus, attention was directed to identifying management deficiencies and evaluating industrial engineering approaches that could be used to cause improvement. The areas of consideration were broadened to include a more comprehensive approach on the utility of industrial engineering practices from design through quality control.

GENERAL CONCLUSIONS

In Sections V through VIII, the applicability of industrial engineering techniques to the following activities were considered: design and operation, maintenance, staffing, and quality control. In each section, specific recommendations were made concerning the applicability of certain industrial engineering techniques to one of the above activities; these are summarized in Table 1 and Figure 1 presented earlier. It is seen from this table that several of the techniques are common to all activities. Figure 1 shows the interrelationships between the various techniques and the expected results.

In the interest of clarity, some of the minor relationships between techniques were not shown in Figure 1 . Of prime significance is the fact that the use of all or most of the techniques enables a designer or manager to rationally and logically develop a design, detailed operating and maintenance management programs, and a staffing level starting from a definition of process goals. In effect, therefore, the total approach shown in Figure 1 provides the procedural framework whereby good management practices can be developed and instituted. This is particularly important in the wastewater treatment field where very little information is available to the plant manager from either technical literature, professional societies, or regulatory agencies on how he should manage the plant.

The "Federal Guidelines" (Ref. 8) require, among other things, the following from new plants:

> Facilities should be planned for maximum reliability
>
> Facilities should be capable of operating during certain failure modes
>
> A thorough analysis should be made of operation and maintenance requirements, including staffing, operator qualifications, and operating budget
>
> Plant bypasses should not be permitted
>
> Designs should provide for efficiency and convenience in O&M and maximum flexibility
>
> Plants should be designed for ease in routine maintenance
>
> Operation and maintenance manuals should be prepared
>
> An effective equipment maintenance program is required including a control system and a spare parts inventory
>
> Larger plants should have a maintenance management system for recording and evaluating data

As stated above, there is little information available on how to meet these requirements. The approach outlined in Figure 1 provides an overall approach which would satisfy all of the above needs.

It is recommended, therefore, that a management manual be prepared to outline the steps required for developing better management practices for both new and existing plants based upon the techniques applied in this study. This manual should be organized in such a manner as to impress the reader with the importance of good managerial control in the various critical areas such as operation, maintenance, quality control, etc. This is an aspect of waste treatment technology which has been sorely neglected in the past. With the exception of the mathematics involved in the R&M model, the techniques evaluated in this program do not require special knowledge or talents that are not commonly available from most managerial level personnel.

During the course of the study, management approaches used in industry were compared to those generally found in the waste treatment field. In some areas, particularly reliability modelling and quality control, there were certain technical deficiencies which either limited the applicability of the approach or prevented good management priorities from being achieved. Among these are:

> Quality goals are not normally stated by regulatory agencies in a manner which reflects the natural variability of the biological treatment process.
>
> The primary measurement of effluent quality, BOD, is not effective as a quality control parameter.
>
> The major process control parameter, food-to-microorganism ratio, is not directly measured since no on-line analytical techniques are available for measuring viable bacteria or BOD content.
>
> Little information is available on the variability of biological treatment performance. It is, therefore, difficult to determine whether substandard performance is due to equipment or operator failure, design deficiencies, inhibitory substances, or the natural cyclical nature of biological processes.
>
> Essentially no data are available on the short-term effects of equipment failure on effluent quality in secondary systems. This prevents the Reliability Model from being used to predict process failures, defined in terms of pollutant concentrations, as a function of equipment failures.

Some of the above conclusions have been stated by others on various occasions; the reason for emphasizing them in this section is that they prevent the development of highly effective management programs.

RECOMMENDATIONS

The following is a summary of the major recommendations generated during this study.

Flint Sewage Treatment Plant

> Develop standard operating procedures to complement the current management practices and to aid in training.

Develop operation cost accounting and maintenance control systems based upon the indexing system developed in this study.

Use several of the techniques and documents prepared for the plant as part of the case study as training aids.

Prepare preventive maintenance procedure cards to ensure proper performance of PM functions and to better assess PM manpower requirements.

Add additional maintenance personnel (electrician) to upgrade the PM program for electrical equipment.

Consider the assignment of additional preventive maintenance tasks to the operators as suggested by the results of the multiple activity chart.

Develop a rapid and comprehensive in-service training program to ease the problems caused by high turnover rate.

Immediate or Short-Term Application

Develop a management manual for designers or managers which gives detailed instructions on the application of techniques for developing sound operation and maintenance management programs. This would provide procedures for satisfying the requirements of the "Federal Guidelines" (Ref. 8).

Develop Functional Staging Diagrams and partially completed Equipment Staging Diagrams and Function-Capability-Equipment Matrices for a variety of secondary treatment processes. These standard documents could then be used, completed, and submitted with the application for construction assistance funds. This would provide a checklist for the regulatory agencies and the designer and would also generate an equipment list with entries indexed according to a standard code.

The collection of data on equipment failure and repair should be required of treatment plants receiving federal construction assistance. These data should include: equipment index number, date and time of failure, reason for failure, perceived effect on process performance, time repaired, time and manpower required for repair. This requirement will promote better maintenance programs and will serve as a data base for reliability and maintainability evaluation programs.

Future Programs

A state-of-the-art study on secondary treatment should be performed to identify the caused of variability of effluent quality and to develop the quantitative relationships describing the nonsteady state effects of equipment failure on effluent quality.

A state-of-the-art study of on-line process control is recommended in order to promote the development of techniques to enhance quality control in waste treatment plants. Included should be consideration of alternate analytical approaches to: (1) describe and analyze effluent quality; and (2) analyze critical process control parameters such as the food-to-microorganism ratio. Consideration should also be given to methods of generating incentives for advanced technique development and plant utilization.

Cost/benefit studies should be initiated on the feasibility of incorporating additional process steps to minimize variations in sewage flow and strength as well as means to prevent release of substandard effluent.

The practicality and advisability of uniform quality reporting formats should be investigated. This study should also investigate data collection and handling systems for documenting the performance of individual plants.

A demonstration project for the application of the industrial engineering techniques evaluated in this program on a plant under design is recommended. It is suggested that this program be complete in that it start with process goals and proceed through the development of staffing levels, standard operating procedures, maintenance programs, and quality control programs. This work should be done for both a conventional plant and an advanced waste treatment installation.

Development of a computerized data collection and evaluation system to be used by regulatory agencies for handling data on equipment failures is recommended. This system would receive maintenance data from a large number of plants and keep an up-to-date tabulation of mean time to failure and mean time to repair. This would form the basis of a data bank for R&M analysis. At the same time, procedures should be developed to enable manufacturers to demonstrate the R&M characteristics of new equipment.

Of all of the above recommendations, the ones dealing with the development of a management manual and the studies for better understanding of the secondary processes (control, effluent quality, and equipment failure effects) are considered most important. Without adequate process technology and effective management, consistently high performance from biological waste treatment plants will be very difficult to attain.

SECTION XII

ACKNOWLEDGEMENTS

A significant amount of time was spent at the Flint, Michigan Sewage Treatment Plant in order to collect data for the Case Study. Sincere thanks are extended to Mr. Robert Misekow, Plant Supervisor; Mr. David Swenson, Assistant Supervisor; Mr. Don Cole, Maintenance Supervisor; Mr. L. Stevens, Operator-Foreman; and all of the other people at the Flint Plant, who have a difficult, sometimes thankless job to do, yet found the time to be helpful, understanding, and patient during our visits.

In addition, thanks are extended to Mr. R. Culp, Plant Superintendent, and Mr. E. Hardie, Chief Operator, of the South Tahoe Waste Treatment Plant for their great assistance during a comparatively brief but intensive visit. The support of the project by the Office of Research and Monitoring of the Environmental Protection Agency and the guidance provided by Mr. Walter F. McMichael, Project Officer, and Mr. Morton S. Ettelstein, Division of Manpower and Training, is acknowledged with sincere appreciation.

Significant contributions were made by the Stanwick Corporation of Arlington, Virginia, as the principal subcontractor on this project. Stanwick personnel participated jointly with Hittman Associates in the plant visits, analysis, and the development of this report. The assistance and review comments provided by Grover Barkdoll, H. B. Maynard & Co., Inc., are gratefully acknowledged.

SECTION XIII

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SECTION XIV
APPENDICES

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APPENDIX A

FUNCTIONAL STAGING DIAGRAMS

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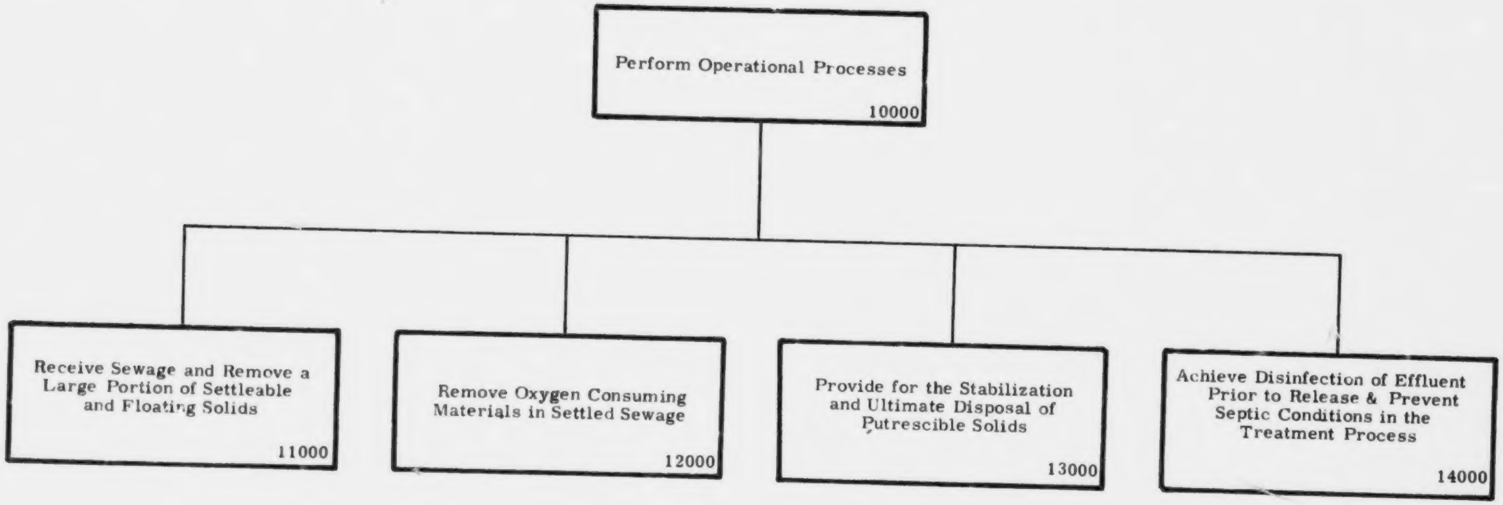
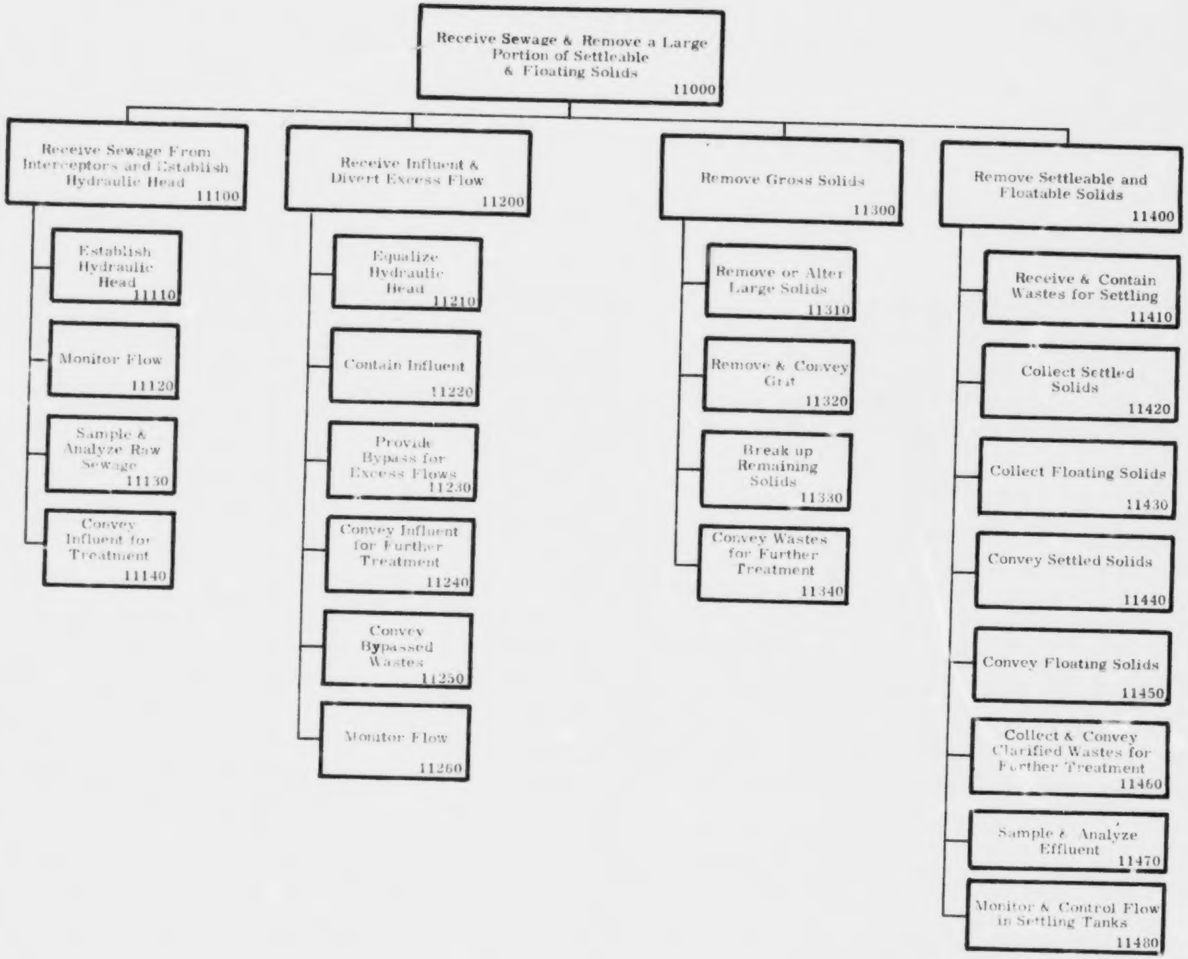
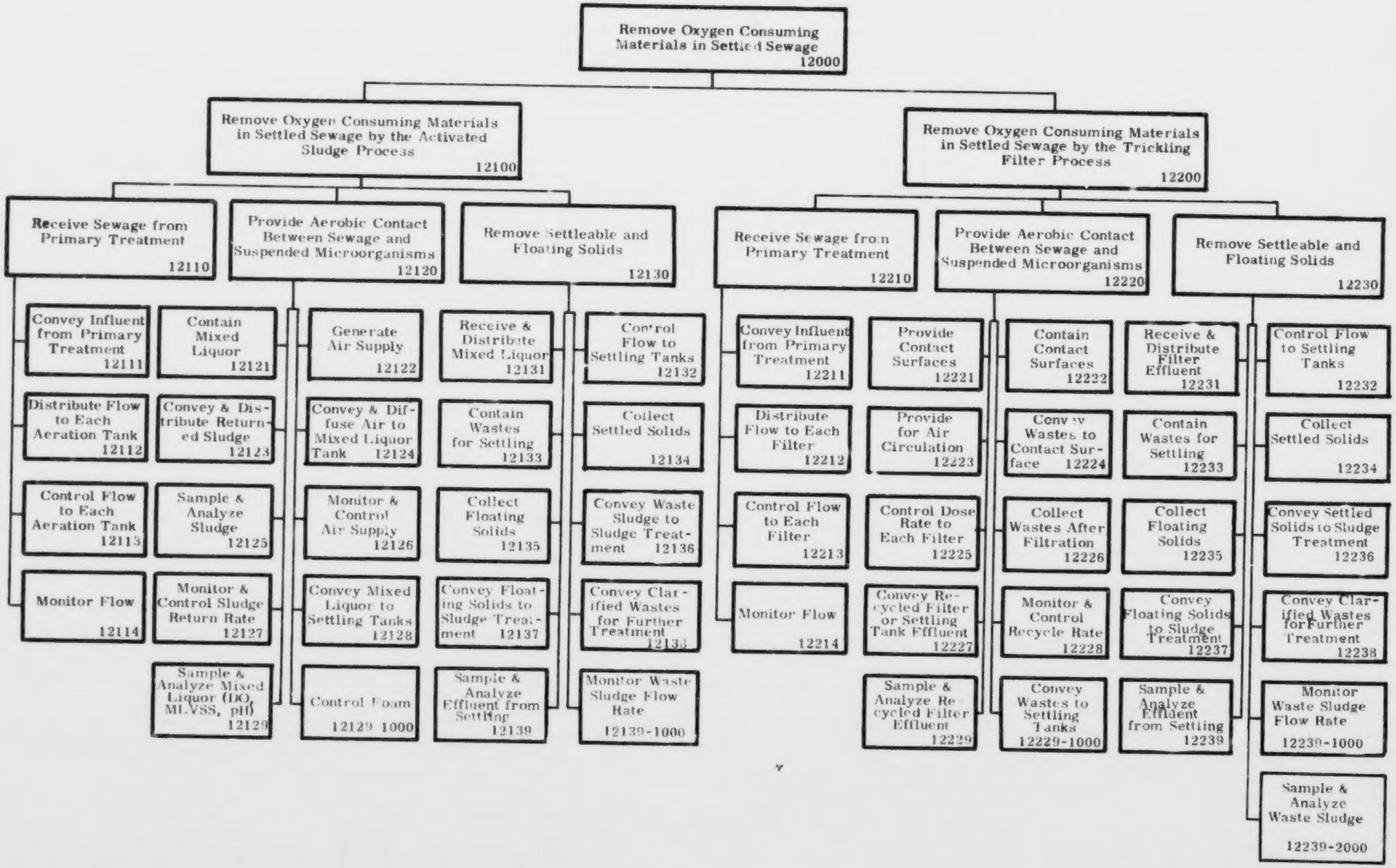

Perform Operational Processes
10000
Receive Sewage and Remove a Large Portion of Settleable and Floating Solids
11000
Remove Oxygen Consuming Materials in Settled Sewage
12000
Provide for the Stabilization and Ultimate Disposal of Putrescible Solids
13000
Achieve Disinfection of Effluent Prior to Release & Prevent Septic Conditions in the Treatment Process
14000

FUNCTIONAL STAGING DIAGRAM (FSD) (sheet 1 of 5)

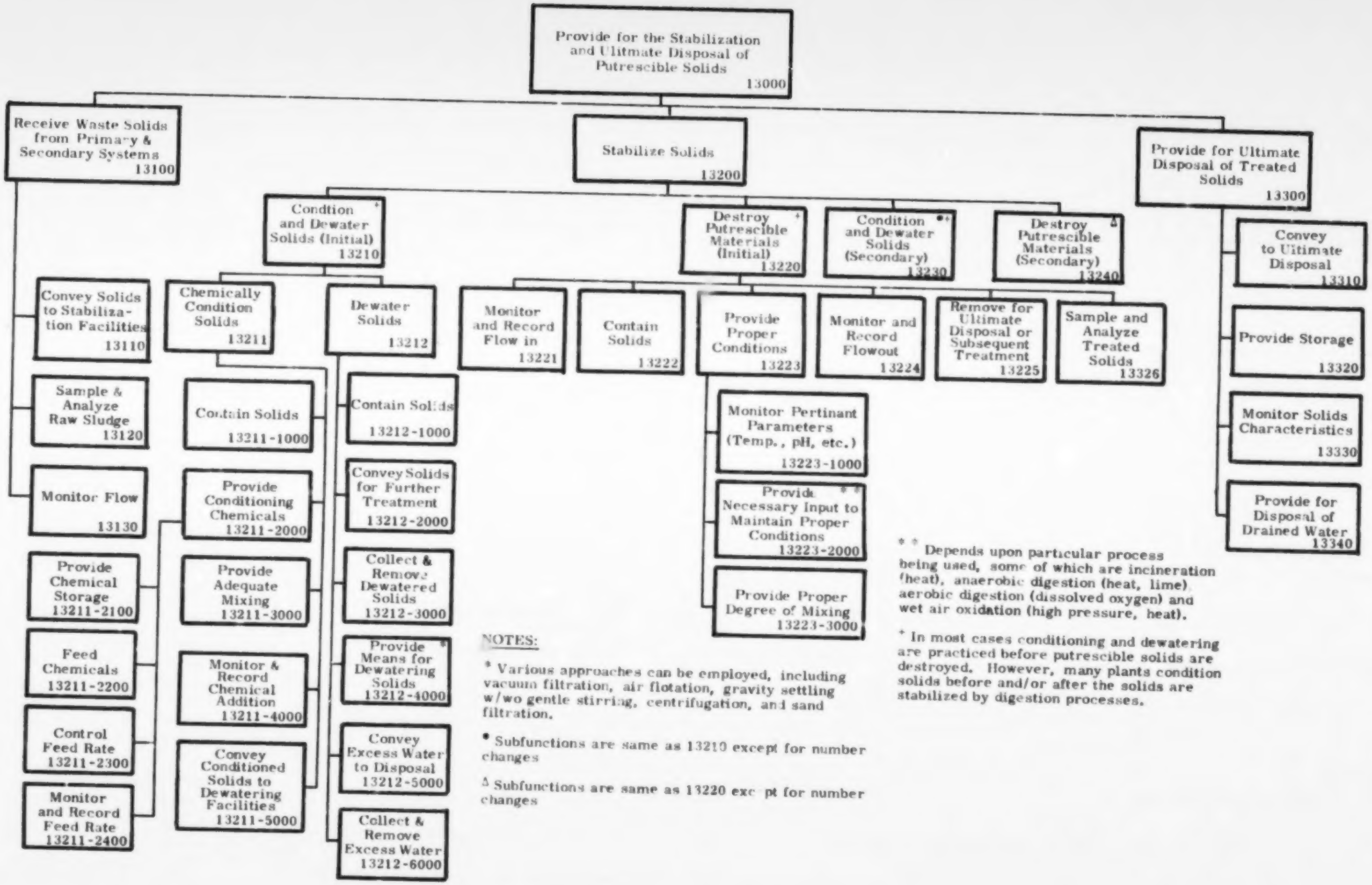

Receive Sewage & Remove a Large Portion of Settleable & Floating Solids 11000
Receive Sewage From Interceptors and Establish Hydraulic Head 11100
Establish Hydraulic Head 11110
Monitor Flow 11120
Sample & Analyze Raw Sewage 11130
Convey Influent for Treatment 11140
Receive Influent & Divert Excess Flow 11200
Equalize Hydraulic Head 11210
Contain Influent 11220
Provide Bypass for Excess Flows 11230
Convey Influent for Further Treatment 11240
Convey Bypassed Wastes 11250
Monitor Flow 11260
Remove Gross Solids 11300
Remove or Alter Large Solids 11310
Remove & Convey Grit 11320
Break up Remaining Solids 11330
Convey Wastes for Further Treatment 11340
Remove Settleable and Floatable Solids 11400
Receive & Contain Wastes for Settling 11410
Collect Settled Solids 11420
Collect Floating Solids 11430
Convey Settled Solids 11440
Convey Floating Solids 11450
Collect & Convey Clarified Wastes for Further Treatment 11460
Sample & Analyze Effluent 11470
Monitor & Control Flow in Settling Tanks 11480

FUNCTIONAL STAGING DIAGRAM (FSD) (Continued) (sheet 2 of 5)


Remove Oxygen Consuming Materials in Settled Sewage 12000
Remove Oxygen Consuming Materials in Settled Sewage by the Activated Sludge Process 12100
Remove Oxygen Consuming Materials in Settled Sewage by the Trickling Filter Process 12200
Receive Sewage from Primary Treatment 12110
Provide Aerobic Contact Between Sewage and Suspended Microorganisms 12120
Remove Settleable and Floating Solids 12130
Receive Sewage from Primary Treatment 12210
Provide Aerobic Contact Between Sewage and Suspended Microorganisms 12220
Remove Settleable and Floating Solids 12230
Convey Influent from Primary Treatment 12111
Distribute Flow to Each Aeration Tank 12112
Control Flow to Each Aeration Tank 12113
Monitor Flow 12114
Contain Mixed Liquor 12121
Convey & Distribute Returned Sludge 12123
Sample & Analyze Sludge 12125
Monitor & Control Sludge Return Rate 12127
Sample & Analyze Mixed Liquor (DO, MLVSS, pH) 12129
Generate Air Supply 12122
Convey & Diffuse Air to Mixed Liquor Tank 12124
Monitor & Control Air Supply 12126
Convey Mixed Liquor to Settling Tanks 12128
Control Foam 12129 1000
Receive & Distribute Mixed Liquor 12131
Contain Wastes for Settling 12133
Collect Floating Solids 12135
Convey Floating Solids to Sludge Treatment 12137
Sample & Analyze Effluent from Settling 12139
Control Flow to Settling Tanks 12132
Collect Settled Solids 12134
Convey Waste Sludge to Sludge Treatment 12136
Convey Clarified Wastes for Further Treatment 12138
Monitor Waste Sludge Flow Rate 12139-1000
Convey Influent from Primary Treatment 12211
Distribute Flow to Each Filter 12212
Control Flow to Each Filter 12213
Monitor Flow 12214
Provide Contact Surfaces 12221
Provide for Air Circulation 12223
Control Dose Rate to Each Filter 12225
Convey Recycled Filter or Settling Tank Effluent 12227
Sample & Analyze Recycled Filter Effluent 12229
Contain Contact Surfaces 12222
Convey Wastes to Contact Surface 12224
Collect Wastes After Filtration 12226
Monitor & Control Recycle Rate 12228
Convey Wastes to Settling Tanks 12229-1000
Receive & Distribute Filter Effluent 12231
Contain Wastes for Settling 12233
Collect Floating Solids 12235
Convey Floating Solids to Sludge Treatment 12237
Sample & Analyze Effluent from Settling 12239
Control Flow to Settling Tanks 12232
Collect Settled Solids 12234
Convey Settled Solids to Sludge Treatment 12236
Convey Clarified Wastes for Further Treatment 12238
Monitor Waste Sludge Flow Rate 12239-1000
Sample & Analyze Waste Sludge 12239-2000

FUNCTIONAL STAGING DIAGRAM (FSD)
(Continued)

(sheet 3 of 5)


Provide for the Stabilization and Ultimate Disposal of Putrescible Solids 13000
Receive Waste Solids from Primary & Secondary Systems 13100
Convey Solids to Stabilization Facilities 13110
Sample & Analyze Raw Sludge 13120
Monitor Flow 13130
Stabilize Solids 13200
Condtion and Dewater Solids (Initial) 13210 +
Chemically Condition Solids 13211
Contain Solids 13211-1000
Provide Conditioning Chemicals 13211-2000
Provide Chemical Storage 13211-2100
Feed Chemicals 13211-2200
Control Feed Rate 13211-2300
Monitor and Record Feed Rate 13211-2400
Provide Adequate Mixing 13211-3000
Monitor & Record Chemical Addition 13211-4000
Convey Conditioned Solids to Dewatering Facilities 13211-5000
Dewater Solids 13212
Contain Solids 13212-1000
Convey Solids for Further Treatment 13212-2000
Collect & Remove Dewatered Solids 13212-3000
Provide Means for Dewatering Solids 13212-4000 *
Convey Excess Water to Disposal 13212-5000
Collect & Remove Excess Water 13212-6000
Destroy Putrescible Materials (Initial) 13220 +
Monitor and Record Flow in 13221
Contain Solids 13222
Provide Proper Conditions 13223
Monitor Pertinant Parameters (Temp., pH, etc.) 13223-1000
Provide Necessary Input to Maintain Proper Conditions 13223-2000 **
Provide Proper Degree of Mixing 13223-3000
Monitor and Record Flowout 13224
Remove for Ultimate Disposal or Subsequent Treatment 13225
Sample and Analyze Treated Solids 13326
Condition and Dewater Solids (Secondary) 13230 •+
Destroy Putrescible Materials (Secondary) 13240 Δ
Provide for Ultimate Disposal of Treated Solids 13300
Convey to Ultimate Disposal 13310
Provide Storage 13320
Monitor Solids Characteristics 13330
Provide for Disposal of Drained Water 13340

NOTES:

* Various approaches can be employed, including vacuum filtration, air flotation, gravity settling w/wo gentle stirring, centrifugation, and sand filtration.

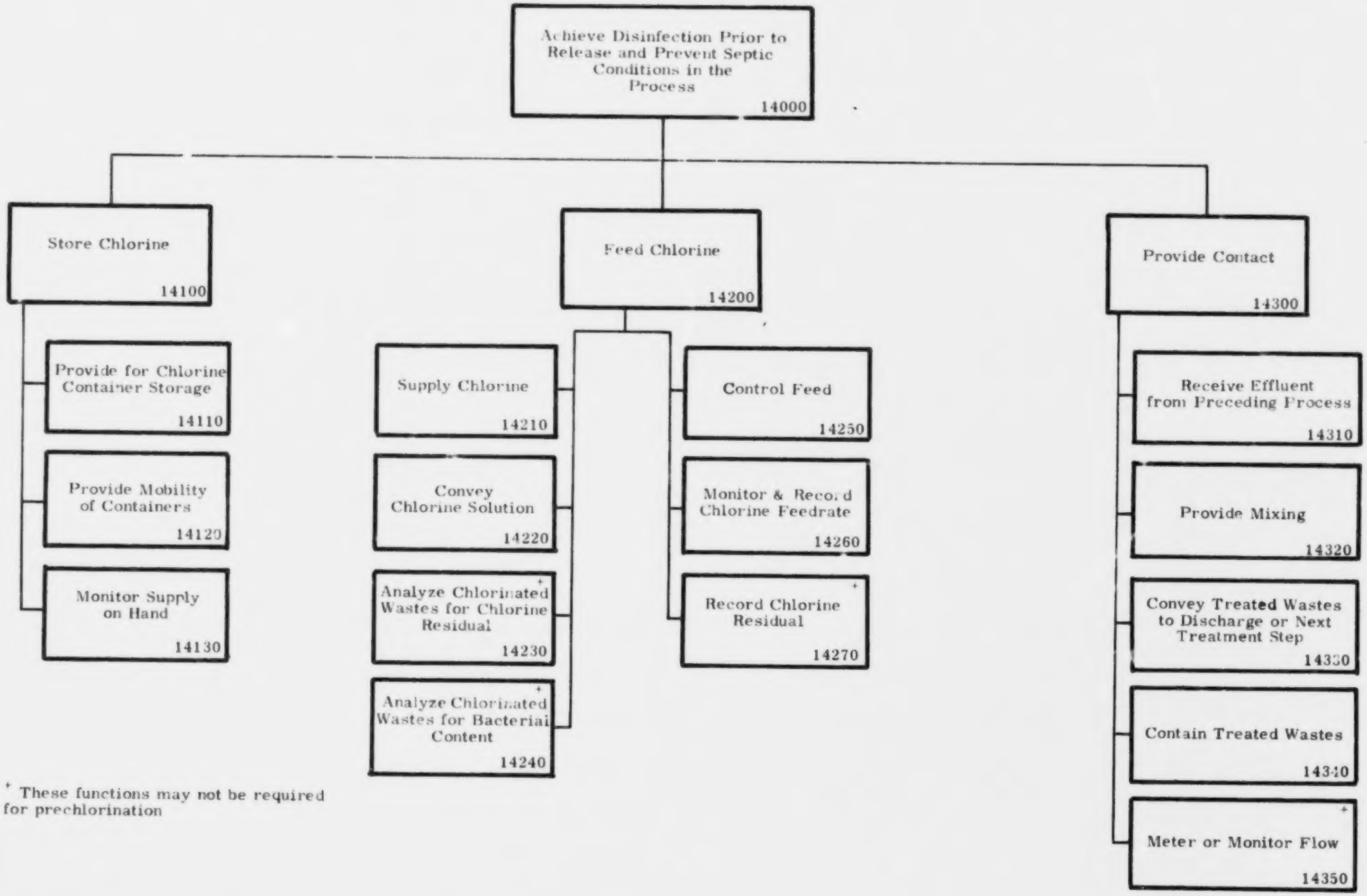
• Subfunctions are same as 13210 except for number changes

Δ Subfunctions are same as 13220 except for number changes

** Depends upon particular process being used, some of which are incineration (heat), anaerobic digestion (heat, lime) aerobic digestion (dissolved oxygen) and wet air oxidation (high pressure, heat).

+ In most cases conditioning and dewatering are practiced before putrescible solids are destroyed. However, many plants condition solids before and/or after the solids are stabilized by digestion processes.

FUNCTIONAL STAGING DIAGRAM (FSD) (sheet 4 of 5)


Achieve Disinfection Prior to Release and Prevent Septic Conditions in the Process
14000
Store Chlorine
14100
Provide for Chlorine Container Storage
14110
Provide Mobility of Containers
14120
Monitor Supply on Hand
14130
Feed Chlorine
14200
Supply Chlorine
14210
Convey Chlorine Solution
14220
Analyze Chlorinated Wastes for Chlorine Residual ⁺
14230
Analyze Chlorinated Wastes for Bacterial Content ⁺
14240
Control Feed
14250
Monitor & Record Chlorine Feedrate
14260
Record Chlorine Residual ⁺
14270
Provide Contact
14300
Receive Effluent from Preceding Process
14310
Provide Mixing
14320
Convey Treated Wastes to Discharge or Next Treatment Step
14330
Contain Treated Wastes
14340
Meter or Monitor Flow ⁺
14350

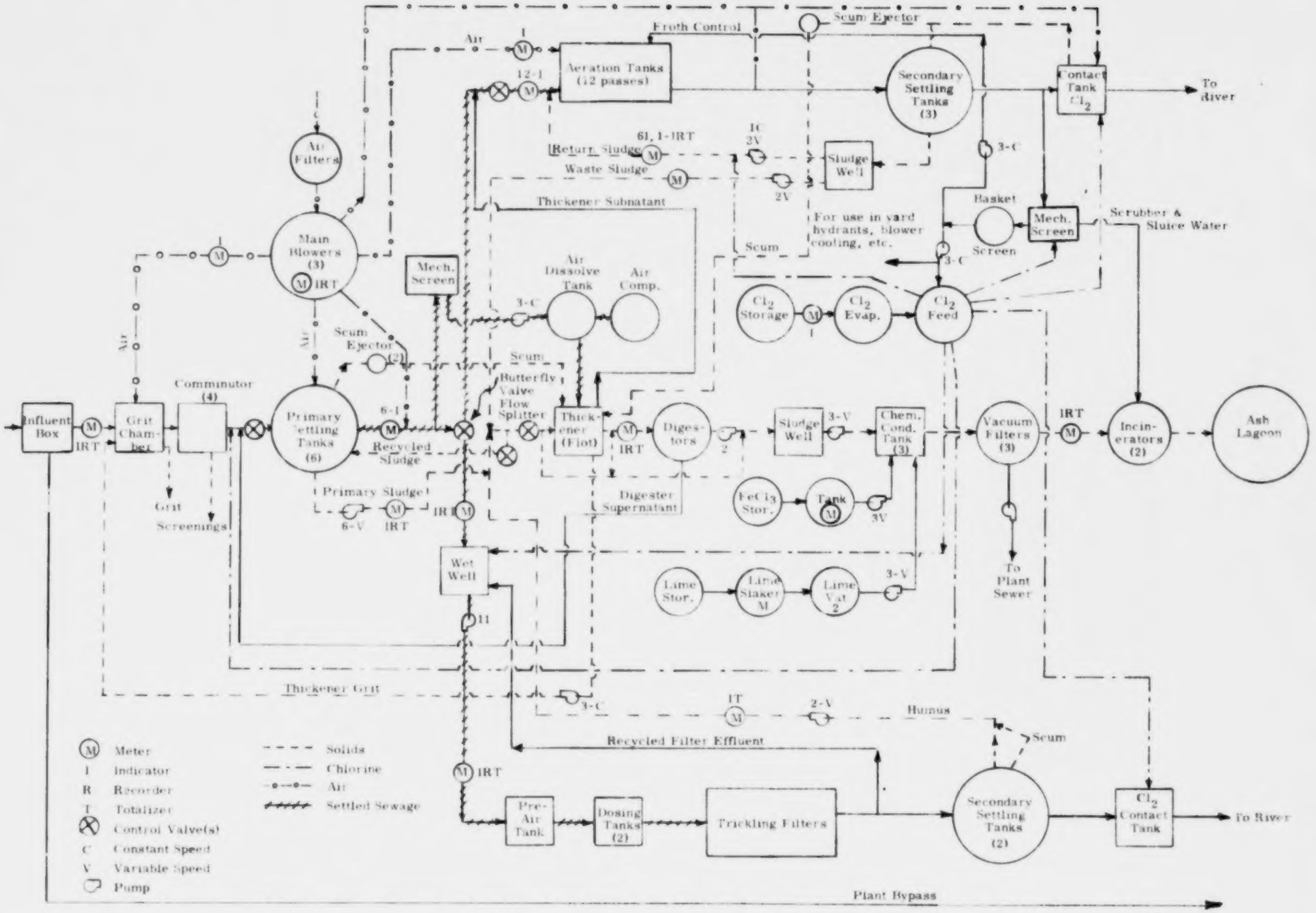
⁺ These functions may not be required for prechlorination

FUNCTIONAL STAGING DIAGRAM (FSD)
(Continued)

(sheet 5 of 5)

APPENDIX B

PROCESS FLOW SCHEMATIC
SEWAGE TREATMENT PLANT
FLINT, MICHIGAN

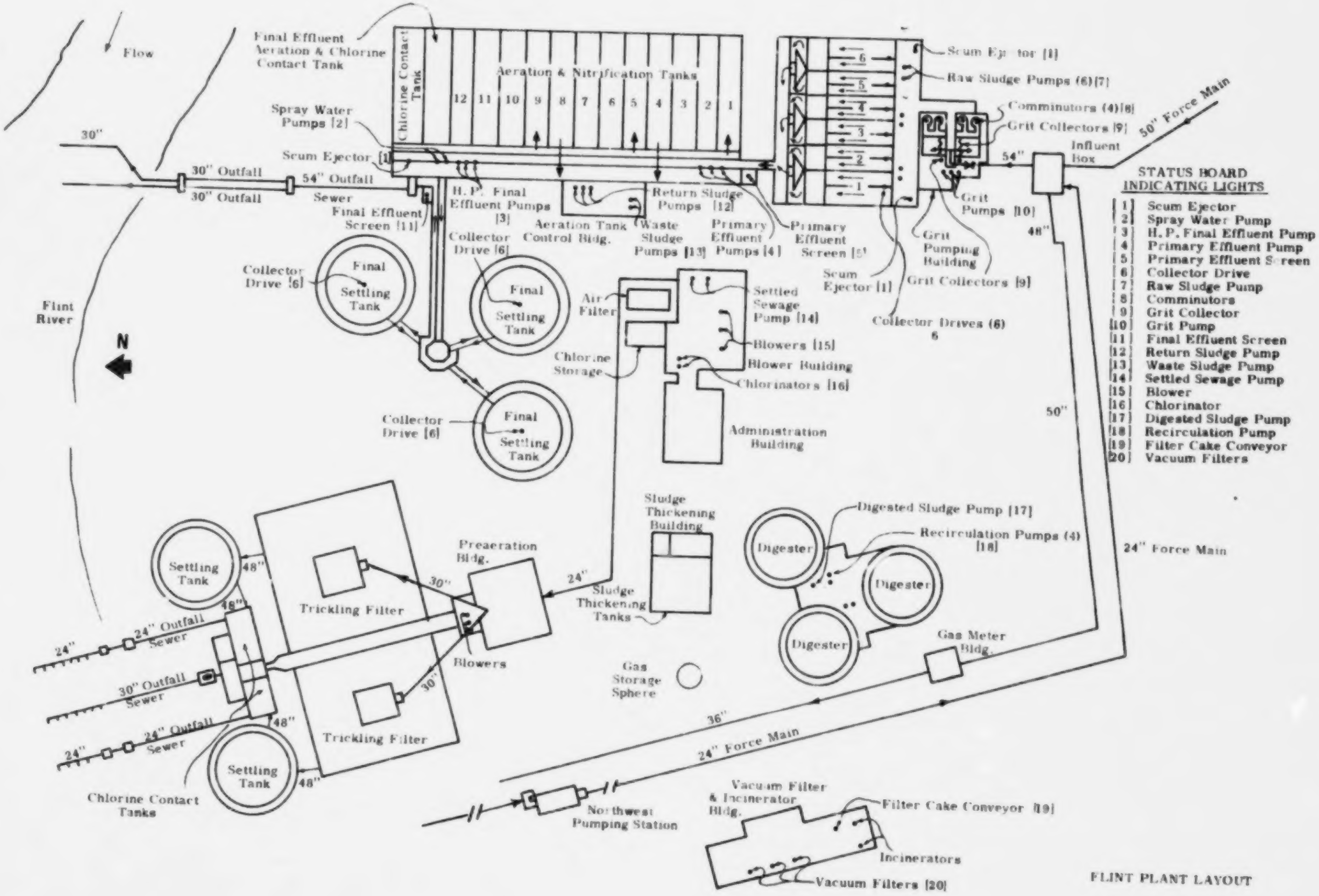

Influent Box
IRT
Grit Chamber
Air
Comminutor (4)
Grit
Screenings
Air Filters
Main Blowers (3)
IRT
Air
Scum Ejector (2)
Primary Settling Tanks (6)
6-I
Recycled Sludge
Primary Sludge
6-V
IRT
Mech. Screen
Air
12-I
Aeration Tanks (12 passes)
Froth Control
Return Sludge
6I, 1-IRT
Waste Sludge
1C 2V
2V
Sludge Well
Thickener Subnatant
Air Dissolve Tank
Air Comp.
3-C
Scum
Butterfly Valve Flow Splitter
Thickener (Flot)
IRT
Digesters
2
Digester Supernatant
Sludge Well
3-V
Chem. Cond. Tank (3)
FeCl3 Stor.
Tank
3V
Lime Stor.
Lime Slaker M
Lime Vat 2
3-V
Scum Ejector
Secondary Settling Tanks (3)
3-C
Contact Tank Cl2
To River
For use in yard hydrants, blower cooling, etc.
Scum
3-C
Cl2 Storage
Cl2 Evap.
Cl2 Feed
Basket Screen
Mech. Screen
Scrubber & Sluice Water
Vacuum Filters (3)
To Plant Sewer
IRT
Incinerators (2)
Ash Lagoon
IRT
Wet Well
11
Thickener Grit
3-C
IT
2-V
Humus
Scum
Recycled Filter Effluent
IRT
Pre-Air Tank
Dosing Tanks (2)
Trickling Filters
Secondary Settling Tanks (2)
Cl2 Contact Tank
To River
Plant Bypass
Meter
I Indicator
R Recorder
T Totalizer
Control Valve(s)
C Constant Speed
V Variable Speed
Pump
Solids
Chlorine
Air
Settled Sewage

PROCESS FLOW SCHEMATIC
FLINT SEWAGE TREATMENT PLANT

(sheet 1 of 1)

APPENDIX C

PHYSICAL LAYOUT
SEWAGE TREATMENT PLANT
FLINT, MICHIGAN

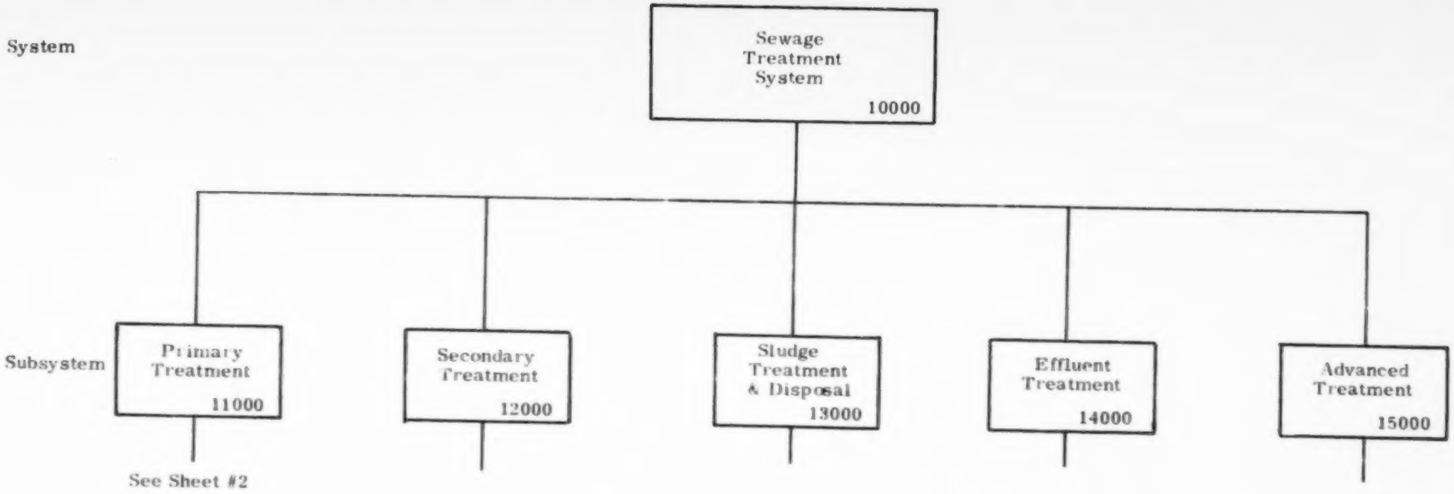

Flow
30"
30" Outfall
30" Outfall
54" Outfall
Sewer
Flint River
N
Final Effluent Aeration & Chlorine Contact Tank
Chlorine Contact Tank
Spray Water Pumps [2]
Scum Ejector [1]
Aeration & Nitrification Tanks
12
11
10
9
8
7
6
5
4
3
2
1
H. P. Final Effluent Pumps [3]
Final Effluent Screen [11]
Aeration Tank Control Bldg.
Waste Sludge Pumps [13]
Return Sludge Pumps [12]
Primary Effluent Pumps [4]
Primary Effluent Screen [5]
Scum Ejector [1]
Raw Sludge Pumps (6) [7]
Comminutors (4) [8]
Grit Collectors [9]
50" Force Main
54"
Influent Box
Grit Pumps [10]
48"
Grit Pumping Building
Grit Collectors [9]
Scum Ejector [1]
Collector Drives (6)
6
Collector Drive [6]
Final Settling Tank
Collector Drive [6]
Final Settling Tank
Collector Drive [6]
Final Settling Tank
Air Filter
Chlorine Storage
Settled Sewage Pump [14]
Blowers [15]
Blower Building
Chlorinators [16]
Administration Building
50"
STATUS BOARD INDICATING LIGHTS
[1] Scum Ejector
[2] Spray Water Pump
[3] H. P. Final Effluent Pump
[4] Primary Effluent Pump
[5] Primary Effluent Screen
[6] Collector Drive
[7] Raw Sludge Pump
[8] Comminutors
[9] Grit Collector
[10] Grit Pump
[11] Final Effluent Screen
[12] Return Sludge Pump
[13] Waste Sludge Pump
[14] Settled Sewage Pump
[15] Blower
[16] Chlorinator
[17] Digested Sludge Pump
[18] Recirculation Pump
[19] Filter Cake Conveyor
[20] Vacuum Filters
Settling Tank
48"
Trickling Filter
Preaeration Bldg.
30"
24"
Blowers
30"
Trickling Filter
24"
24" Outfall Sewer
48"
30" Outfall Sewer
24" Outfall Sewer
24"
48"
Settling Tank
48"
Chlorine Contact Tanks
Sludge Thickening Building
Sludge Thickening Tanks
Gas Storage Sphere
Digester
Digester
Digester
Digested Sludge Pump [17]
Recirculation Pumps (4) [18]
24" Force Main
Gas Meter Bldg.
36"
24" Force Main
Northwest Pumping Station
Vacuum Filter & Incinerator Bldg.
Filter Cake Conveyor [19]
Incinerators
Vacuum Filters [20]
FLINT PLANT LAYOUT

FLINT PLANT LAYOUT

(sheet 1 of 1)

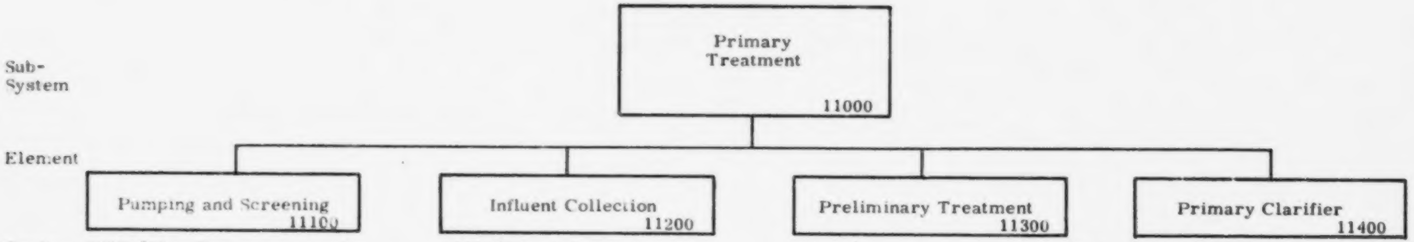
APPENDIX D

SYSTEM/EQUIPMENT STAGING DIAGRAMS


System
Sewage Treatment System
10000
Subsystem
Primary Treatment
11000
See Sheet #2
Secondary Treatment
12000
Sludge Treatment & Disposal
13000
Effluent Treatment
14000
Advanced Treatment
15000

SYSTEM/EQUIPMENT STAGING DIAGRAM

Sheet 1 of 12


Sub-
System
Primary
Treatment
11000
Element
Pumping and Screening
11100
Influent Collection
11200
Preliminary Treatment
11300
Primary Clarifier
11400
Equip-
ment

11100/01 Raw sewage mains
/02 Pump station set well
/03 Sewage pumps and motors
/04 Pump motor controls
/05 Piping and check values
/06 Flow meter and recorder
/07 Sample jars, sampling pole, and jar carrying container
/08 Laboratory equipment

11200/01 Influent pipes
/02 Influent collection chamber
/03 Overflow weirs
/04 Overflow channel
/05 Sluice gate or valve
/06 Valve operating device
/07 Influent pipe to grit tanks
/08 By-pass chamber
/09 By-pass pipe
/10 Flow meter

11300/01 Bar screen (and rake)
/02 Grit tanks
/03 Grit removal mechanism
/04 Sewage flow control
/05 Grit pumps
/06 Influent and effluent piping
/07 Weirs
/08 Air compressors
/09 Air piping and valves
/10 Air drops and diffusers
/11 Comminutor chamber
/12 Comminutors
/13 Control and by-pass devices (stop plates, valves etc.)
/14 Trash removal
/15 Influent and effluent piping or channels
/16 Effluent piping or channels
/17 Control valves or plates

11400/01 Influent channel
/02 Distribution pipes for all wastes to be settled (raw sewage, re-cycled waste sludge from primary/secondary)
/03 Settling tanks
/04 Air piping and controls
/05 Air diffusers
/06 Sewage control valves and gates
/07 Meter (sewage flow to each clarifier)
/08 Sludge scraper mechanism
/09 Sludge pumps (primary)
/10 Control valves (sludge)
/11 Piping (sludge) in settling tank
/12 Meter (sludge)
/13 Scum collection mechanism
/14 Scum collection trough
/15 Scum removal pump (ejector)
/16 Scum control valves gates etc.

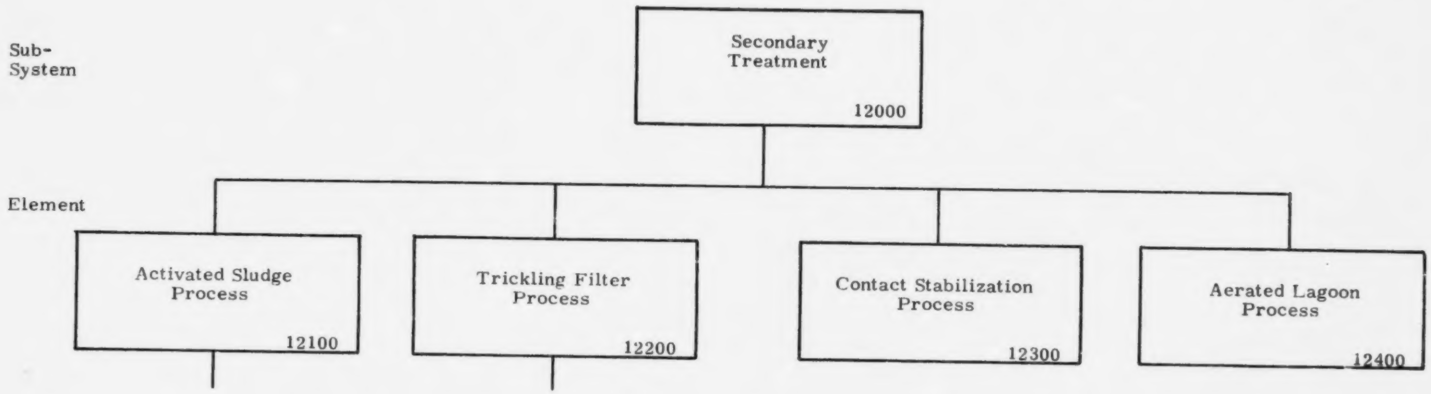
SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 2 of 12

11400/17	Scum piping in settling tanks
/18	Sludge piping to sludge disposal
/19	Sludge valves
/20	Scum piping to scum disposal
/21	Scum valves
/22	Primary treatment effluent channel
/23	Effluent valves and gates
/24	Weirs
/25	Laboratory (D.), suspended solids, volatile suspended solids, BOD, PH)
/26	Flow measuring device (settled sewage)
/27	Indicating meter

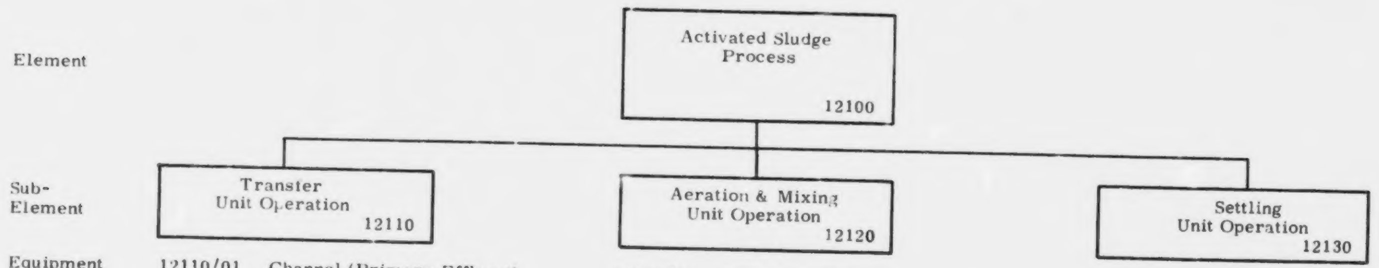
SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 3 of 12


Sub-
System
Element
Secondary
Treatment
12000
Activated Sludge
Process
12100
Trickling Filter
Process
12200
Contact Stabilization
Process
12300
Aerated Lagoon
Process
12400

SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 4 of 12


Element
Sub-Element
Activated Sludge Process
12100
Transfer Unit Operation
12110
Aeration & Mixing Unit Operation
12120
Settling Unit Operation
12130

Equipment

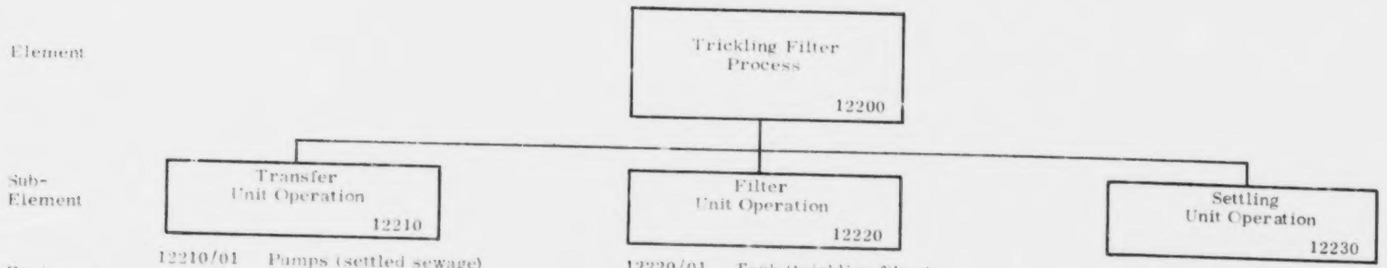
12110/01 Channel (Primary Effluent)
/02 Flow control valves & piping (primary effluent)
/03 Meter (flow)
/04 Air compressor
/05 Piping (pneumatic instrument air)
/06 Filter (air compressor)
/07 Piping (primary effluent)
/08 Water screens
/09 Pump (primary effluent to thickeners)

12120/01 Tank (aeration)
/02 Blowers
/03 Filters (air)
/04 Meter (air cym)
/05 Flow control valves (air)
/06 Diffusers (air)
/07 Piping (air)
/08 Pump (cooling water)
/09 Meter (return sludge gpm)
/10 Flow control valves (return sludge)
/11 Trough (mixed liquor)
/12 Foam spray system (pump, pipi, nozzles, etc.)
/13 Protected water system
/14 Laboratory analysis system (dissolved oxygen, mixed liquor suspended solids, mixed liquor volatile suspended solids, pH)

12130/01 Tanks (final clarifier)
/02 Control valves (mixed liquor)
/03 Scum removal mechanism
/04 Scum removal pump/ejector
/05 Piping (scum)
/06 Sludge scraper mechanism
/07 Sludge well
/08 Pumps (return sludge)
/09 Piping (return sludge)
/10 Trough (secondary effluent)
/11 Laboratory analysis system (dissolved oxygen, BOD, suspended solids, pH, NH_3, TKN, NO_3, index, sludge % solids)
/12 Piping (settled sludge)

SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 5 of 12


Element
Sub-Element
Equipment
Trickling Filter Process
12200
Transfer Unit Operation
12210
Filter Unit Operation
12220
Settling Unit Operation
12230

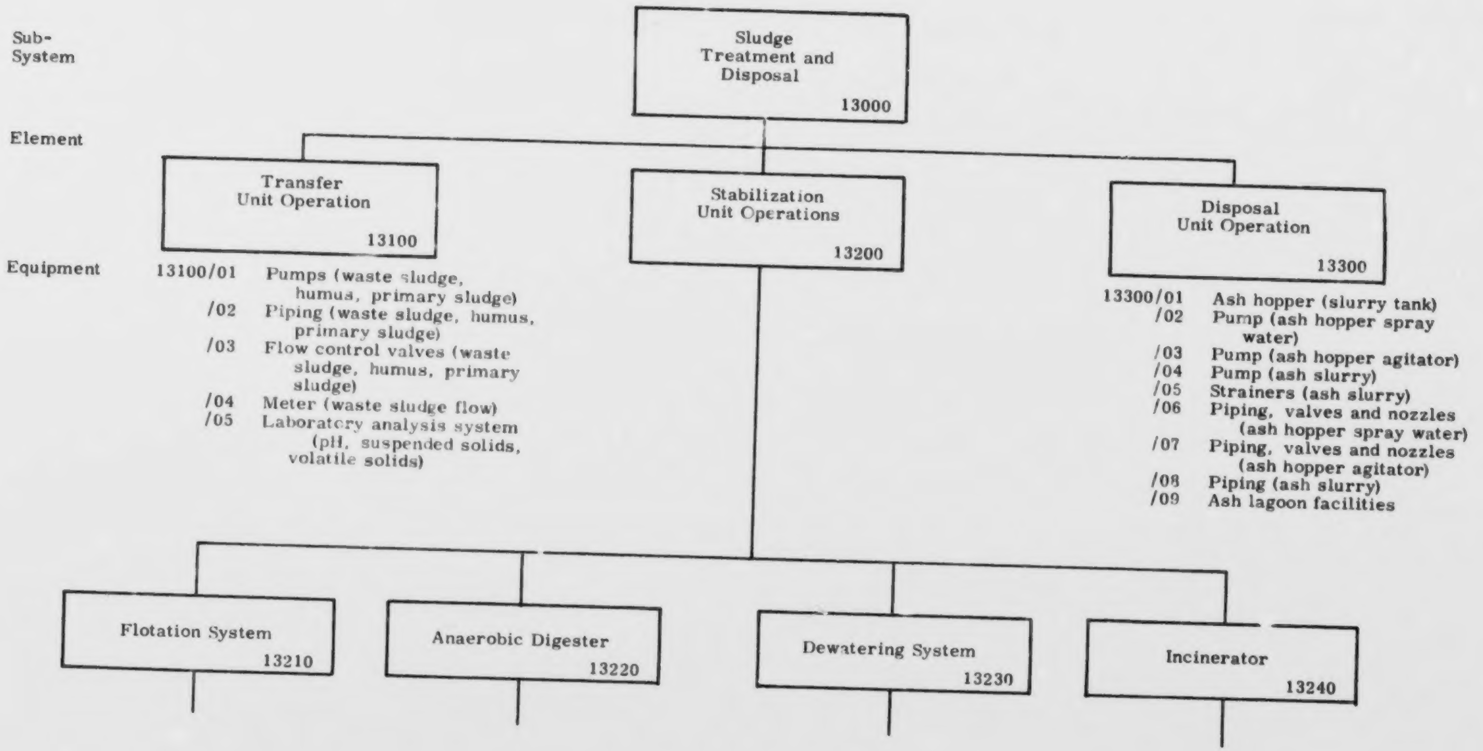
12210/01 Pumps (settled sewage)
/02 Wet well (settled sewage)
/03 Piping (settled sewage)
/04 Meter (settled sewage flow)
/05 Pre-air tank
/06 Air compressor
/07 Filter (air)
/08 Piping (air)
/09 Diffuser (air)
/10 Meter (air psi, & cfm)

12220/01 Tank (trickling filter)
/02 Tank false bottom
/03 Filter media
/04 Dosing mechanisms
/05 Dosing distribution piping
/06 Dosing nozzles
/07 Collecting manifold (filter underdrain)
/08 Piping (filter effluent)
/09 Piping (recycled filter effluent)
/10 Valves (recycled filter effluent)
/11 Meter (recycled filter effluent flow)
/12 Laboratory analysis system (BOD, dissolved oxygen, suspended solids, pH)

12230/01 Tank (final clarifiers)
/02 Scum removal mechanism
/03 Scum removal pump
/04 Piping (scum)
/05 Sludge scraper mechanism
/06 Sludge well
/07 Pump (waste sludge)
/08 Piping (waste sludge)
/09 Meter (waste sludge flow)
/10 Trough (trickling filter effluent)
/11 Control valve (effluent)
/12 Laboratory analysis system (BOD, dissolved oxygen, suspended solids, pH, NH_3, NO_3, SDI, SVI, % solids)

SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 6 of 12



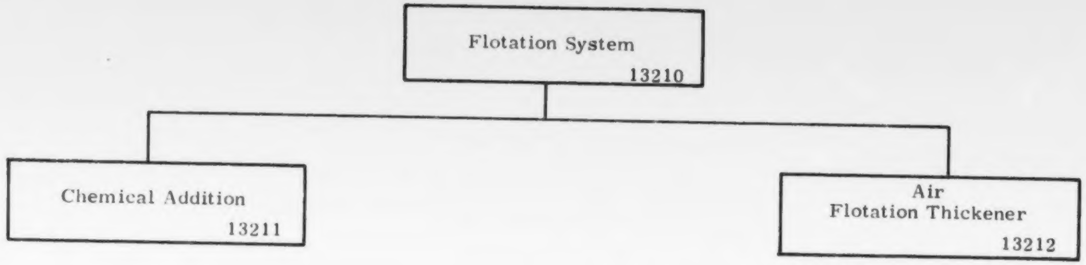
Sub-System
Element
Equipment
Sludge Treatment and Disposal 13000
Transfer Unit Operation 13100
Stabilization Unit Operations 13200
Disposal Unit Operation 13300
Flotation System 13210
Anaerobic Digester 13220
Dewatering System 13230
Incinerator 13240

13100/01	Pumps (waste sludge, humus, primary sludge)
/02	Piping (waste sludge, humus, primary sludge)
/03	Flow control valves (waste sludge, humus, primary sludge)
/04	Meter (waste sludge flow)
/05	Laboratory analysis system (pH, suspended solids, volatile solids)

13300/01	Ash hopper (slurry tank)
/02	Pump (ash hopper spray water)
/03	Pump (ash hopper agitator)
/04	Pump (ash slurry)
/05	Strainers (ash slurry)
/06	Piping, valves and nozzles (ash hopper spray water)
/07	Piping, valves and nozzles (ash hopper agitator)
/08	Piping (ash slurry)
/09	Ash lagoon facilities

SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 7 of 12



13212/01	Tank (flotation thickeners)
/02	Sludge skimmer mechanism & controls
/03	Sludge well
/04	Pumps (thickened sludge)
/05	Piping (thickened sludge)
/06	Valves (thickened sludge)
/07	Meter (thickened sludge flow)
/08	Subnatant well
/09	Pumps (thickener subnatant)
/10	Piping (thickener subnatant)
/11	Valves (thickener subnatant)
/12	Grit screw mechanism & controls
/13	Grit scraper mechanism
/14	Grit well
/15	Pump (grit)
/16	Piping (grit)
/17	Valves (grit)
/18	Compressor (flotation air)
/19	Piping & valves (flotation air)
/20	Filter (air compressor)
/21	Pressure tank
/22	Compressor (instrument air)
/23	Piping & valves (instrument air)
/24	Filters & dryers (compressor-instrument air)
/25	Laboratory analysis system (pH, suspended solids, volatile solids)

SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 8 of 12

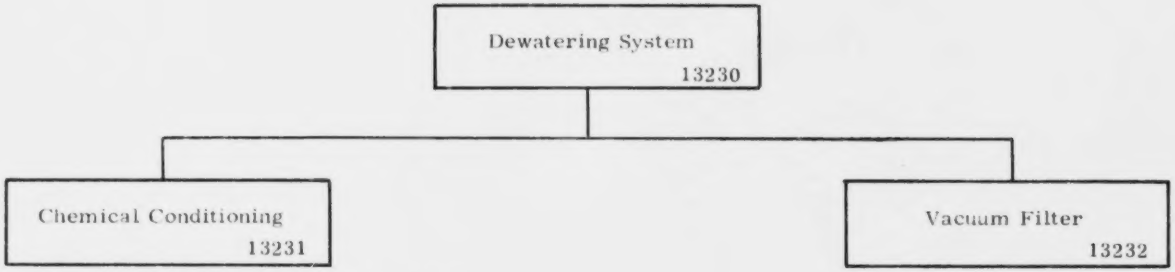
Anaerobic Digester

13220

13220/01	Recorder (waster sludge flow, digested sludge flow)
/02	Tanks (digester)
/03	Meters (temp, waste sludge flow, digested sludge flow)
/04	Piping (waste sludge)
/05	Valves (waste sludge)
/06	Heat exchanger
/07	Pump (recirculating-heater)
/08	Pump (digested sludge transfer)
/09	Piping (digested sludge transfer)
/10	Valves (digested sludge transfer)
/11	Pumps (digested sludge)
/12	Piping (digested sludge)
/13	Valves (digested sludge)
/14	Piping (digester supernatant)
/15	Valves (digester supernatant)
/16	Protected water system (heat exchanger)
/17	Laboratory analysis system (pH, suspended solids, volatile solids)

SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 9 of 12



13231/01	Tank (chemical conditioning)
/02	$FeCl_3$ storage tank
/03	Lime storage tank
/04	Lime feeding mechanism
/05	Lime slaker
/06	Lime solution (slurry) tank
/07	Protected water system
/08	Pump (lime solution)
/09	Piping (lime solution)
/10	Pump ($FeCl_3$ solution)
/11	$FeCl_3$ solution tank
/12	Pump ($FeCl_3$ solution)
/13	Piping ($FeCl_3$ solution)
/14	Piping (conditioned sludge)

13232/01	Vacuum filter unit
/02	Vacuum pump unit, separator and pipint
/03	Protected water system
/04	Pump (filtrate)
/05	Piping (filtrate)
/06	Sludge conveyor velt mechanism
/07	Portable belt conveyor
/08	Compressor (sludge well)
/09	Air filter (sludge well compressor)
/10	Sludge well
/11	Piping & valves (air)
/12	Diffuser (air)
/13	Pump (sludge)
/14	Piping (sludge)
/15	Pump (Calgon feeding)
/16	Piping (Calgon)

SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 10 of 12

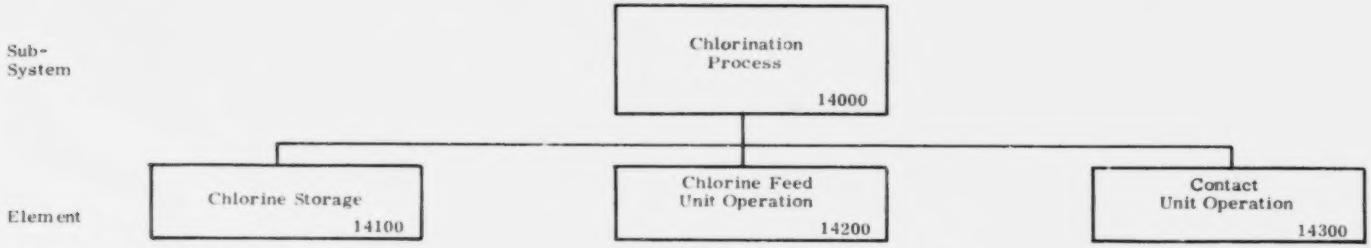
Incinerator

13240

13240/01	Incinerator
/02	Sludge conveyor belt mechanism
/03	Filter cake splitter unit
/04	Weight scales
/05	Recorder (filter cake weight)
/06	Gas (scrubbers)
/07	Pump (scrubber water)
/08	Piping (scrubber water)
/09	Final effluent well
/10	Blower (shaft cooling)
/11	Induced draft fans
/12	Air compressor (service air)
/13	Air filter (air compressor)
/14	Piping & valves (air)

SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 11 of 12


Sub-System
Element
Chlorination Process
14000
Chlorine Storage
14100
Chlorine Feed Unit Operation
14200
Contact Unit Operation
14300

Equipment

14100/01 Storage racks for chlorine cylinders
/02 Weighing scale
/03 Trolley hoist
/04 Cylinder valve connectors

14200/01 Chlorinator (including meters)
/02 Flow control valves and piping (chlorine)
/03 Flow control valves and piping (water)
/04 Meters (vacuum, flow)
/05 Recorder (chlorine feed rate)
/06 Chlorine residual analyzer & recorder)
/07 Ambient chlorine detector
/08 Piping & valves (chlorine solution)
/09 Protected water system
/10 Laboratory analysis system (chlorine residual, coliform bacteria)

14300/01 Contact tank
/02 Chlorine diffuser
/03 Baffles
/04 Piping (final effluent)
/05 Meter (final effluent flow)

SYSTEM/EQUIPMENT STAGING DIAGRAM
(Continued)

Sheet 12 of 12

APPENDIX E

OPERATION SEQUENCE DIAGRAMS

Legend:

Symbols

⇨	Transmission
○	Operation
□	Inspection, Examination
◇	Decision
◡	Combined Inspection and Operation
F⇨	Written Form

Numbers Within Symbols

1 - Every hour, e.g. 1
2 - Every 2 hours
4 - Twice a Shift
8 - Once a Shift
12 - Twice daily
24 - Once daily
48 - Every two days
W - Walk
FPF-3 - Flint Plant Form 3

Preceding page blank

SYSTEM Flint Wastewater Treatment Plant

USE OF WORKSHEET Describe operations performed by operator foreman during two-hourly plant inspections

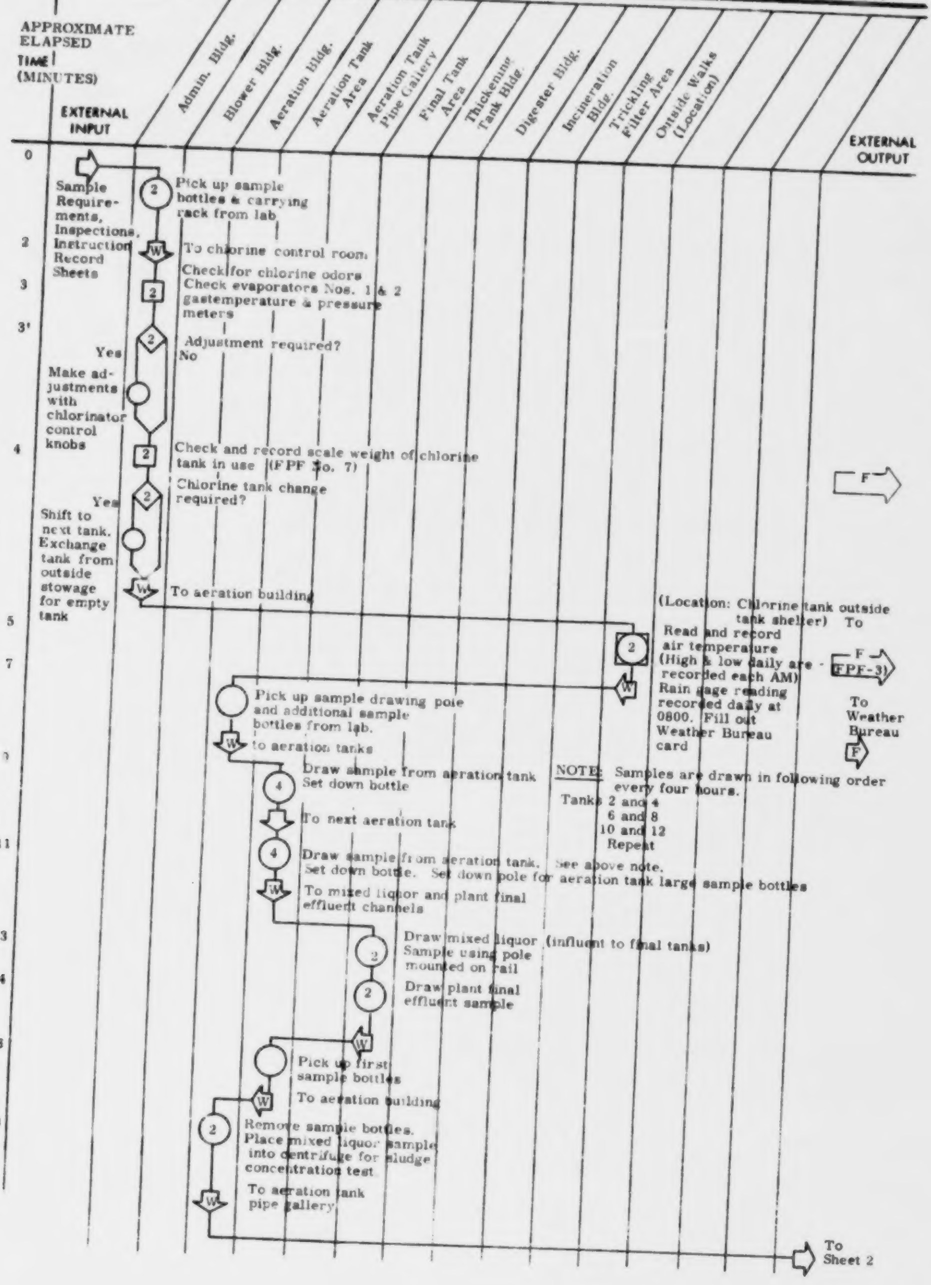
PROJECT TITLE Application of industrial Engineering Techniques

STAGE NO.

SHEET NO. 1 of 4

PREPARED BY G. Calnan

DATE 4/14/71


APPROXIMATE ELAPSED TIME (MINUTES)
EXTERNAL INPUT
Admin. Bldg.
Blower Bldg.
Aeration Bldg.
Aeration Tank Area
Aeration Tank Pipe Gallery
Final Tank Area
Thickening Tank Bldg.
Digester Bldg.
Incineration Bldg.
Trickling Filter Area
Outside Walks (Location)
EXTERNAL OUTPUT
0
2
3
3'
4
5
7
9
11
13
14
16
18
2
W
2
2
Yes
2
2
Yes
W
2
W
W
4
4
W
2
2
W
W
2
W
F
F
FPF-3
F

0 Sample Requirements, Inspections, Instruction Record Sheets

Pick up sample bottles & carrying rack from lab

2 To chlorine control room

3 Check for chlorine odors
Check evaporators Nos. 1 & 2 gastemperature & pressure meters

3' Adjustment required?
No

Yes Make adjustments with chlorinator control knobs

4 Check and record scale weight of chlorine tank in use (FPF No. 7)

Chlorine tank change required?

Yes Shift to next tank. Exchange tank from outside stowage for empty tank

To aeration building

5 (Location: Chlorine tank outside tank shelter)
Read and record air temperature (High & low daily are recorded each AM) Rain gage reading recorded daily at 0800. Fill out Weather Bureau card

To FPF-3

To Weather Bureau

7 Pick up sample drawing pole and additional sample bottles from lab.

To aeration tanks

9 Draw sample from aeration tank
Set down bottle

To next aeration tank

11 Draw sample from aeration tank. Set down bottle. Set down pole for aeration tank large sample bottles See above note.

NOTE: Samples are drawn in following order every four hours.
Tanks 2 and 4
6 and 8
10 and 12
Repeat

To mixed liquor and plant final effluent channels

13 Draw mixed liquor (influent to final tanks) Sample using pole mounted on rail

14 Draw plant final effluent sample

16 Pick up first sample bottles

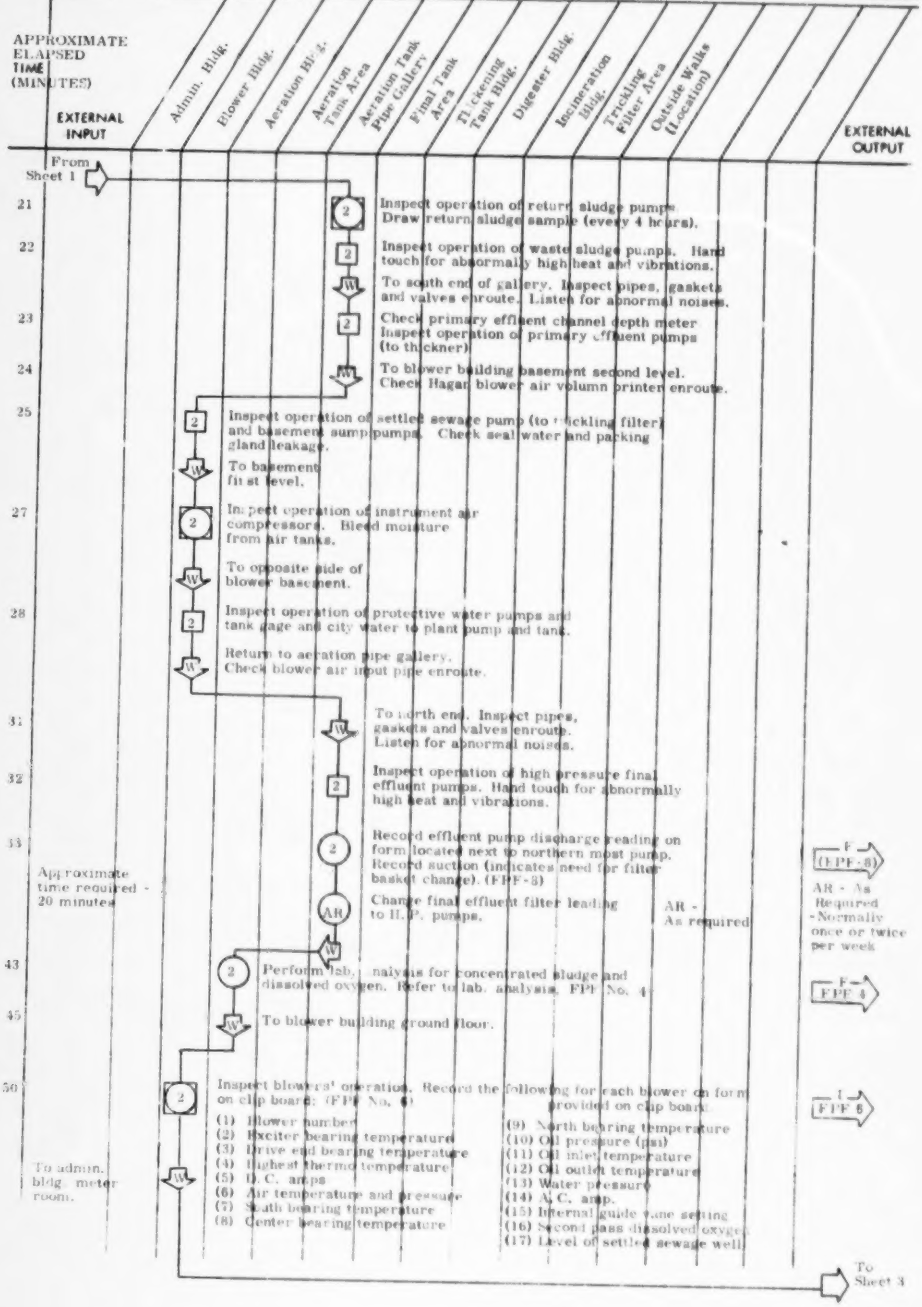
To aeration building

18 Remove sample bottles. Place mixed liquor sample into centrifuge for sludge concentration test

To aeration tank pipe gallery

To Sheet 2

SYSTEM Flint Wastewater Treatment Plant **USE OF WORKSHEET** Describe operations performed by operator foreman during two-hourly plant inspections	**PROJECT TITLE** Application of Industrial Engineering Techniques	**STAGE NO.** - **PREPARED BY** G. Calnan	**SHEET NO.** 2 of 4 **DATE** 4/14/71



APPROXIMATE ELAPSED TIME (MINUTES)
EXTERNAL INPUT
Admin. Bldg.
Blower Bldg.
Aeration Bldg.
Aeration Tank Area
Aeration Tank Pipe Gallery
Final Tank Area
Thickening Tank Bldg.
Digester Bldg.
Incineration Bldg.
Trickling Filter Area
Outside Walks (Location)
EXTERNAL OUTPUT
From Sheet 1
2
W
AR
F (FPF-8)
F FPF 4
I FPF 6
To Sheet 3

21 Inspect operation of return sludge pumps. Draw return sludge sample (every 4 hours).

22 Inspect operation of waste sludge pumps. Hand touch for abnormally high heat and vibrations.

To south end of gallery. Inspect pipes, gaskets and valves enroute. Listen for abnormal noises.

23 Check primary effluent channel depth meter Inspect operation of primary effluent pumps (to thickner)

24 To blower building basement second level. Check Hagan blower air volumn printer enroute.

25 Inspect operation of settled sewage pump (to trickling filter) and basement sump pumps. Check seal water and packing gland leakage.

To basement first level.

27 Inspect operation of instrument air compressors. Bleed moisture from air tanks.

To opposite side of blower basement.

28 Inspect operation of protective water pumps and tank gage and city water to plant pump and tank.

Return to aeration pipe gallery. Check blower air input pipe enroute.

31 To north end. Inspect pipes, gaskets and valves enroute. Listen for abnormal noises.

32 Inspect operation of high pressure final effluent pumps. Hand touch for abnormally high heat and vibrations.

33 Record effluent pump discharge reading on form located next to northern most pump. Record suction (indicates need for filter basket change). (FPF-8)

Approximate time required - 20 minutes

Change final effluent filter leading to H. P. pumps.

AR - As required

AR - As Required - Normally once or twice per week

43 Perform lab. analysis for concentrated sludge and dissolved oxygen. Refer to lab. analysis, FPF No. 4

45 To blower building ground floor.

50 Inspect blowers' operation. Record the following for each blower on form provided on clip board: (FPF No. 6)

(1) Blower number
(2) Exciter bearing temperature
(3) Drive end bearing temperature
(4) Highest thermo temperature
(5) D. C. amps
(6) Air temperature and pressure
(7) South bearing temperature
(8) Center bearing temperature
(9) North bearing temperature
(10) Oil pressure (psi)
(11) Oil inlet temperature
(12) Oil outlet temperature
(13) Water pressure
(14) A. C. amp.
(15) Internal guide vane setting
(16) Second pass dissolved oxygen
(17) Level of settled sewage well

To admin. bldg. meter room.

SYSTEM Flint Wastewater Treatment Plant

USE OF WORKSHEET Describe operations performed by operator foreman during two-hourly plant inspections

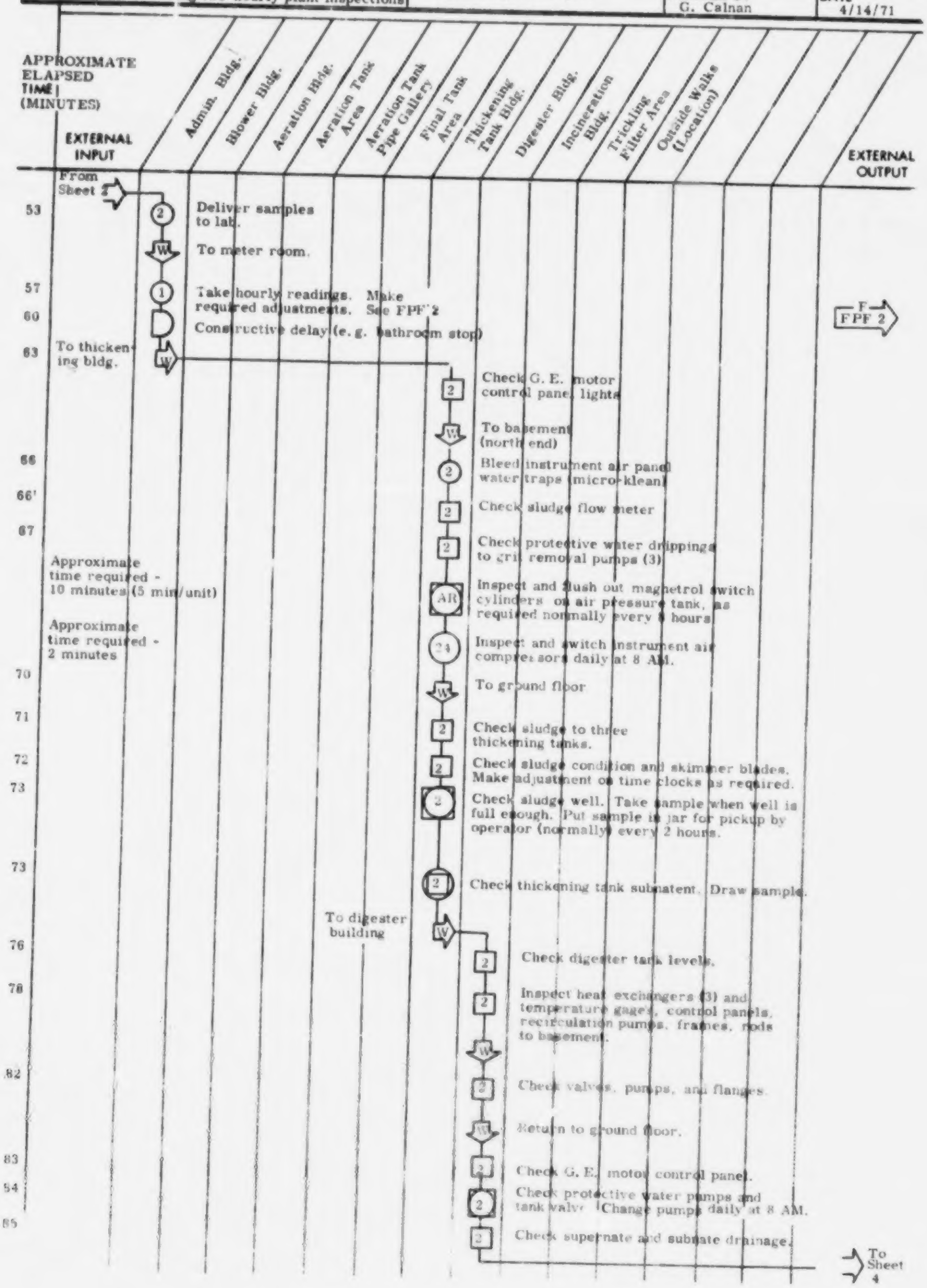
PROJECT TITLE Application of Industrial Engineering Techniques

STAGE NO.

PREPARED BY G. Calnan

SHEET NO. 3 of 4

DATE 4/14/71


APPROXIMATE ELAPSED TIME (MINUTES)
EXTERNAL INPUT
Admin. Bldg.
Blower Bldg.
Aeration Bldg.
Aeration Tank Area
Aeration Tank Pipe Gallery
Final Tank Area
Thickening Tank Bldg.
Digester Bldg.
Incineration Bldg.
Trickling Filter Area
Outside Walks (Location)
EXTERNAL OUTPUT
From Sheet 2
2
W
1
F
FPF 2
AR
24
To Sheet 4

53 Deliver samples to lab.

To meter room.

57 Take hourly readings. Make required adjustments. See FPF 2

60 Constructive delay (e.g. bathroom stop)

63 To thickening bldg.

Check G. E. motor control panel lights

To basement (north end)

66 Bleed instrument air panel water traps (micro-klean)

66' Check sludge flow meter

67 Check protective water drippings to grit removal pumps (3)

Approximate time required - 10 minutes (5 min/unit)

Inspect and flush out magnetrol switch cylinders on air pressure tank, as required normally every 8 hours

Approximate time required - 2 minutes

Inspect and switch instrument air compressors daily at 8 AM.

70 To ground floor

71 Check sludge to three thickening tanks.

72 Check sludge condition and skimmer blades. Make adjustment on time clocks as required.

73 Check sludge well. Take sample when well is full enough. Put sample in jar for pickup by operator (normally) every 2 hours.

73 Check thickening tank subnatent. Draw sample.

To digester building

76 Check digester tank levels.

78 Inspect heat exchangers (3) and temperature gages, control panels, recirculation pumps, frames, rods to basement.

82 Check valves, pumps, and flanges.

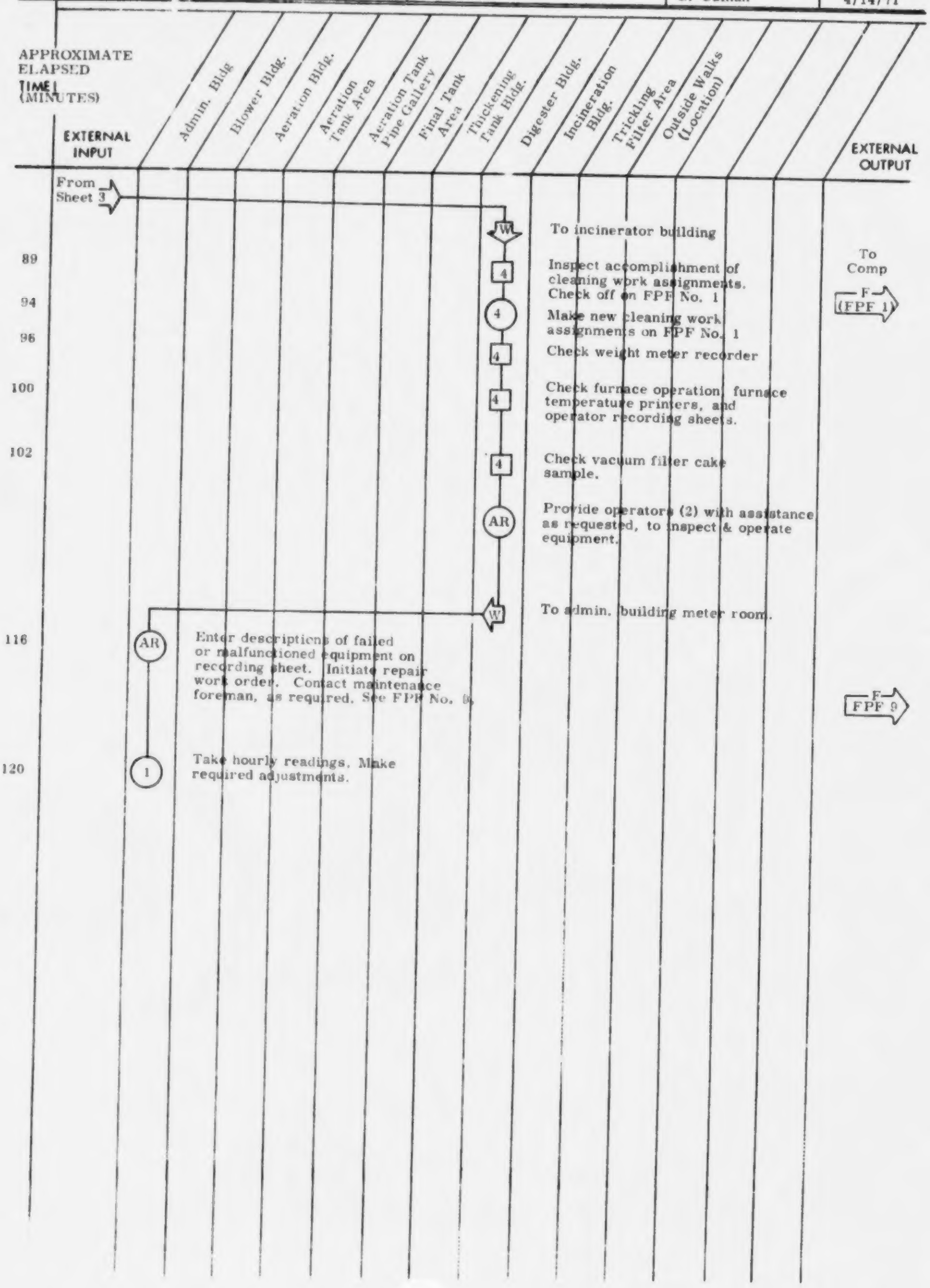
Return to ground floor.

83 Check G. E. motor control panel.

54 Check protective water pumps and tank valve. Change pumps daily at 8 AM.

85 Check supernate and subnate drainage.

SYSTEM Flint Wastewater Treatment Plant	**PROJECT TITLE** Application of Industrial Engineering Techniques	**STAGE NO.** -	**SHEET NO.** 4 of 4
USE OF WORKSHEET Describe operations performed by operator foreman during two-hourly plant inspections		**PREPARED BY** G. Calnan	**DATE** 4/14/71


APPROXIMATE ELAPSED TIME (MINUTES)
EXTERNAL INPUT
Admin. Bldg
Blower Bldg.
Aeration Bldg.
Aeration Tank Area
Aeration Tank Pipe Gallery
Final Tank Area
Thickening Tank Bldg.
Digester Bldg.
Incineration Bldg.
Trickling Filter Area
Outside Walks (Location)
EXTERNAL OUTPUT
From Sheet 3
W
4
4
4
4
4
AR
W
AR
1
To Comp
F (FPF 1)
F FPF 9

To incinerator building

89 Inspect accomplishment of cleaning work assignments. Check off on FPF No. 1

94 Make new cleaning work assignments on FPF No. 1

96 Check weight meter recorder

100 Check furnace operation, furnace temperature printers, and operator recording sheets.

102 Check vacuum filter cake sample.

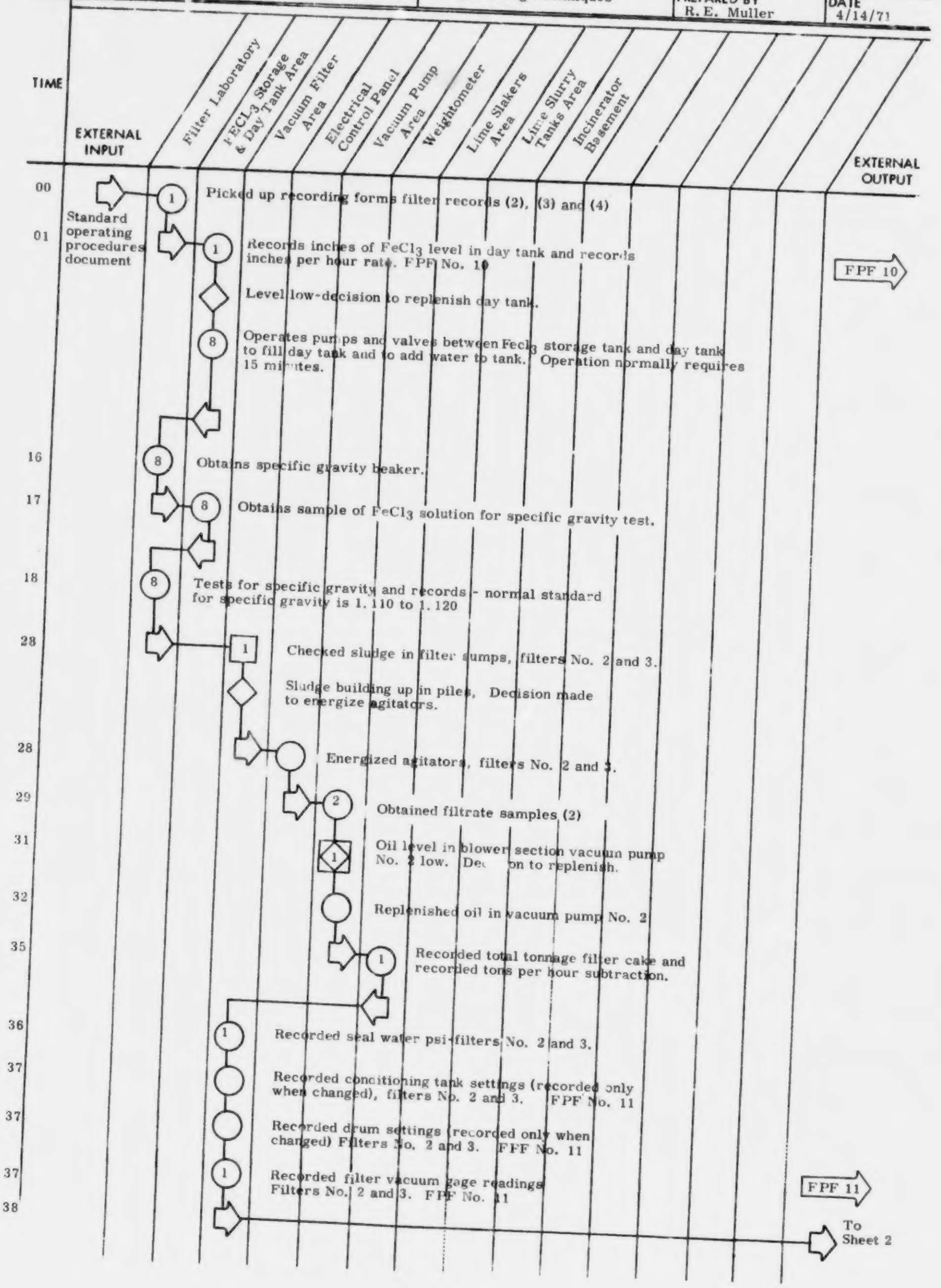
Provide operators (2) with assistance as requested, to inspect & operate equipment.

To admin. building meter room.

116 Enter descriptions of failed or malfunctioned equipment on recording sheet. Initiate repair work order. Contact maintenance foreman, as required. See FPF No. 9

120 Take hourly readings. Make required adjustments.

SYSTEM Filter Operator - Operations	PROJECT TITLE Application of Industrial Engineering Techniques	STAGE NO.	SHEET NO. 1 of 3
USE OF WORKSHEET Flint Sewage Treatment Plant		PREPARED BY R.E. Muller	DATE 4/14/71


TIME
EXTERNAL INPUT
Filter Laboratory
FECL3 Storage & Day Tank Area
Vacuum Filter Area
Electrical Control Panel
Vacuum Pump Area
Weightometer
Lime Slakers Area
Lime Slurry Tanks Area
Incinerator Basement
EXTERNAL OUTPUT
Standard operating procedures document
FPF 10
FPF 11
To Sheet 2

00 Picked up recording forms filter records (2), (3) and (4)

01 Records inches of $FeCl_3$ level in day tank and records inches per hour rate. FPF No. 10

Level low-decision to replenish day tank.

Operates pumps and valves between $FeCl_3$ storage tank and day tank to fill day tank and to add water to tank. Operation normally requires 15 minutes.

16 Obtains specific gravity beaker.

17 Obtains sample of $FeCl_3$ solution for specific gravity test.

18 Tests for specific gravity and records - normal standard for specific gravity is 1.110 to 1.120

28 Checked sludge in filter sumps, filters No. 2 and 3.

Sludge building up in piles, Decision made to energize agitators.

28 Energized agitators, filters No. 2 and 3.

29 Obtained filtrate samples (2)

31 Oil level in blower section vacuum pump No. 2 low. Decision to replenish.

32 Replenished oil in vacuum pump No. 2

35 Recorded total tonnage filter cake and recorded tons per hour subtraction.

36 Recorded seal water psi-filters No. 2 and 3.

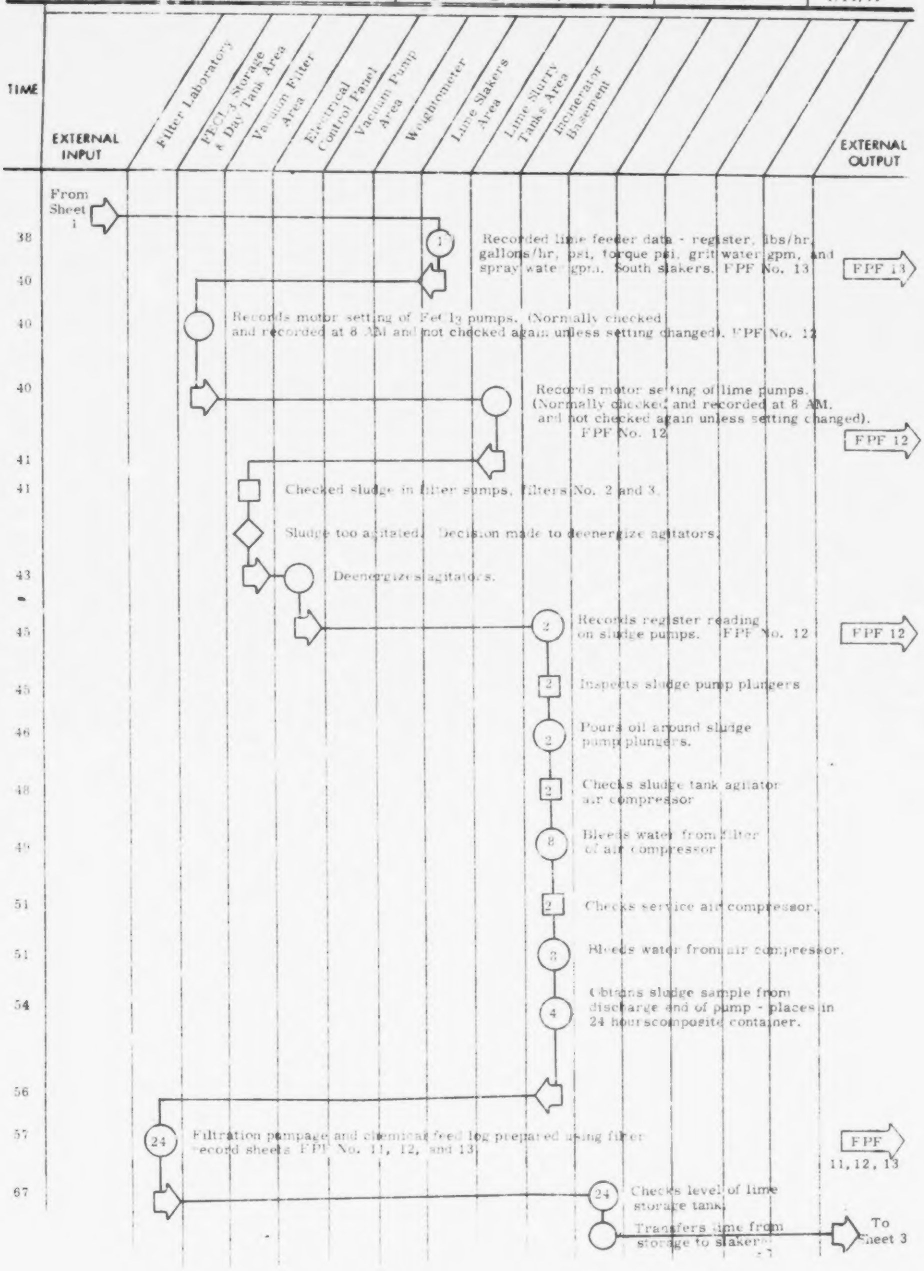
37 Recorded conditioning tank settings (recorded only when changed), filters No. 2 and 3. FPF No. 11

37 Recorded drum settings (recorded only when changed) Filters No. 2 and 3. FPF No. 11

37 Recorded filter vacuum gage readings Filters No. 2 and 3. FPF No. 11

38

SYSTEM Filter Operator - Operations	PROJECT TITLE Application of Industrial Engineering Techniques	STAGE NO.	SHEET NO. 2 of 3
USE OF WORKSHEET Flint Sewage Treatment Plant		PREPARED BY R. E. Muller	DATE 4/14/71


TIME
EXTERNAL INPUT
Filter Laboratory
FECL3 Storage & Day Tank Area
Vacuum Filter Area
Electrical Control Panel
Vacuum Pump Area
Weightometer
Lime Slakers Area
Lime Slurry Tanks Area
Incinerator Basement
EXTERNAL OUTPUT
From Sheet 1
1
FPF 13
FPF 12
2
2
2
2
8
2
3
4
FPF 12
24
FPF 11, 12, 13
24
To Sheet 3

38 Recorded lime feeder data - register, lbs/hr, gallons/hr, psi, torque psi, grit water gpm, and spray water gpm. South slakers. FPF No. 13

40

40 Records motor setting of $FeCl_3$ pumps. (Normally checked and recorded at 8 AM and not checked again unless setting changed). FPF No. 12

40 Records motor setting of lime pumps. (Normally checked and recorded at 8 AM. and not checked again unless setting changed). FPF No. 12

41

41 Checked sludge in filter sumps, Filters No. 2 and 3.

Sludge too agitated. Decision made to deenergize agitators.

43 Deenergizes agitators.

45 Records register reading on sludge pumps. FPF No. 12

45 Inspects sludge pump plungers

46 Pours oil around sludge pump plungers.

48 Checks sludge tank agitator air compressor

49 Bleeds water from filter of air compressor

51 Checks service air compressor.

51 Bleeds water from air compressor.

54 Obtains sludge sample from discharge end of pump - places in 24 hours composite container.

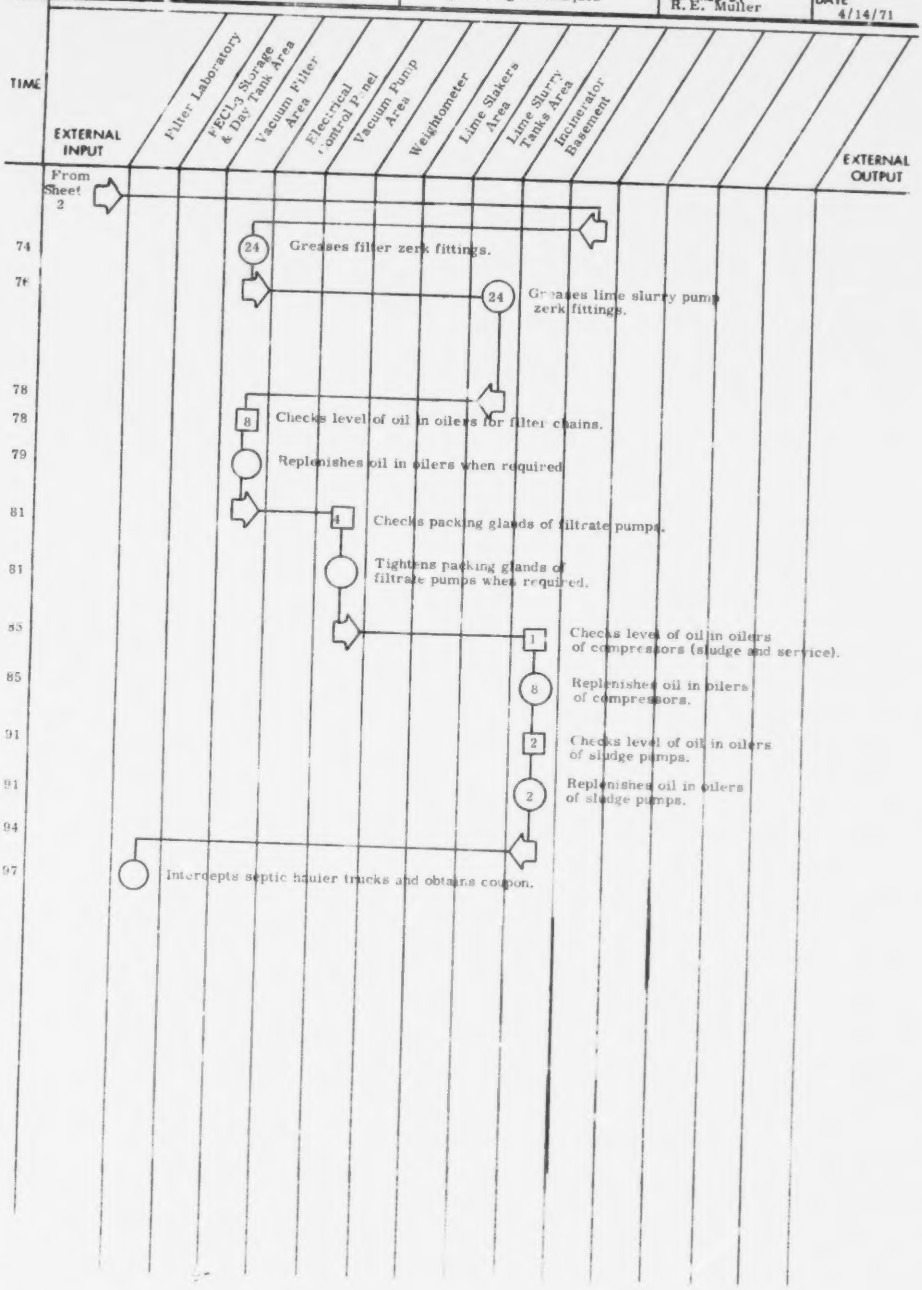
56

57 Filtration pumpage and chemical feed log prepared using filter record sheets FPF No. 11, 12, and 13.

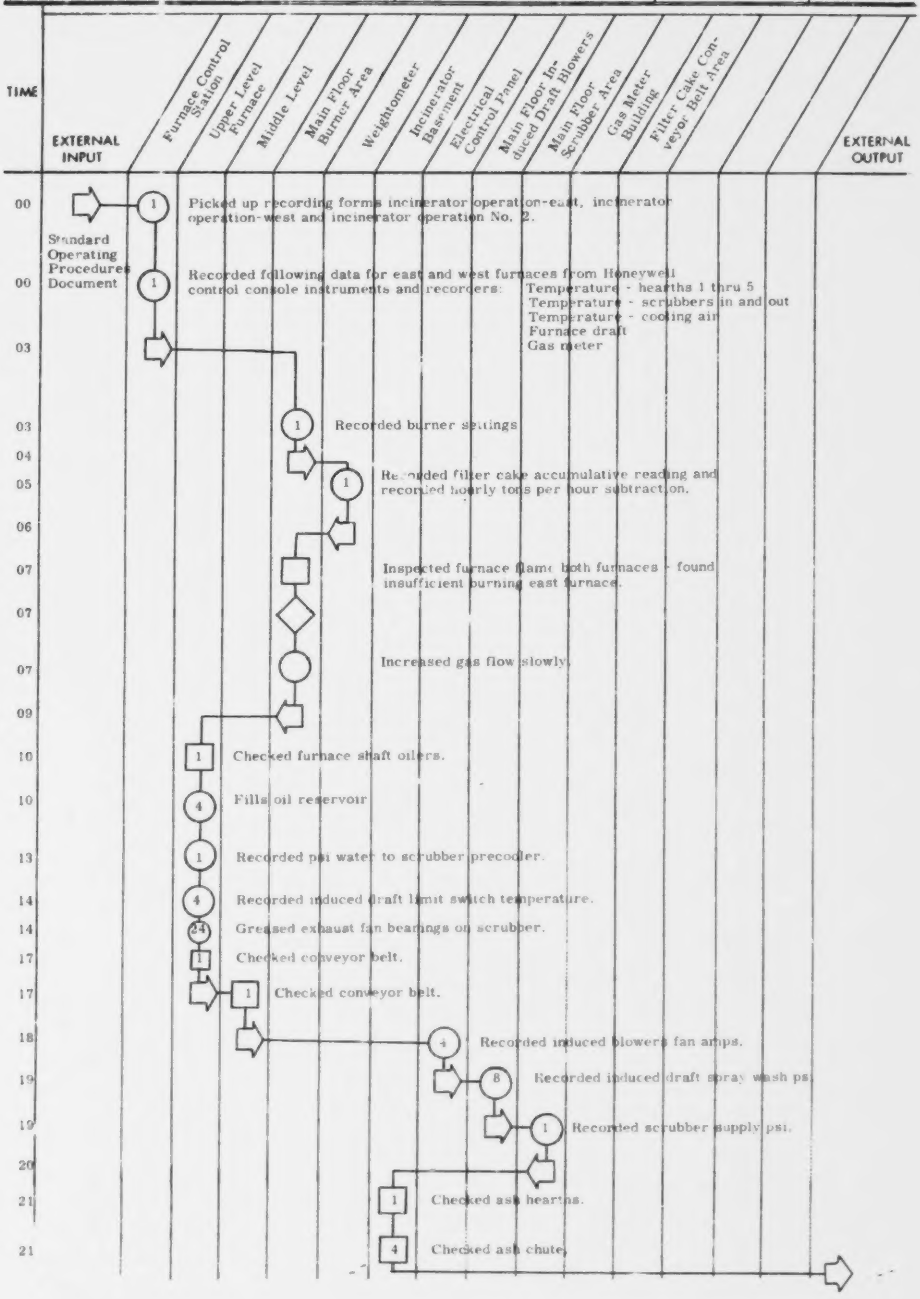
67 Checks level of lime storage tank.

Transfers lime from storage to slakers.

SYSTEM Filter Operator - Operations
USE OF WORKSHEET Flint Sewage Treatment Plant
PROJECT TITLE Application of Industrial Engineering Techniques
STAGE NO. -
SHEET NO. 3 of 3
PREPARED BY R. E. Muller
DATE 4/14/71


TIME
EXTERNAL INPUT
Filter Laboratory
FECl3 Storage & Day Tank Area
Vacuum Filter Area
Electrical Control Panel
Vacuum Pump Area
Weightometer
Lime Slakers Area
Lime Slurry Tanks Area
Incinerator Basement
EXTERNAL OUTPUT
From Sheet 2
74
24
Greases filter zerk fittings.
76
24
Greases lime slurry pump zerk fittings.
78
78
8
Checks level of oil in oilers for filter chains.
79
Replenishes oil in oilers when required.
81
4
Checks packing glands of filtrate pumps.
81
Tightens packing glands of filtrate pumps when required.
85
1
Checks level of oil in oilers of compressors (sludge and service).
85
8
Replenishes oil in oilers of compressors.
91
2
Checks level of oil in oilers of sludge pumps.
91
2
Replenishes oil in oilers of sludge pumps.
94
97
Intercepts septic hauler trucks and obtains coupon.

SYSTEM Furnace Operator - Operations	**PROJECT TITLE** Application of Industrial Engineering Techniques	**STAGE NO.** -	**SHEET NO.** 1 of 2
USE OF WORKSHEET Jim Wezell - Flint Sewage Treatment Plant		**PREPARED BY** R.E. Muller	**DATE** 4/14/71


TIME
EXTERNAL INPUT
Furnace Control Station
Upper Level Furnace
Middle Level
Main Floor Burner Area
Weightometer
Incinerator Basement
Electrical Control Panel
Main Floor Induced Draft Blowers
Main Floor Scrubber Area
Gas Meter Building
Filter Cake Conveyor Belt Area
EXTERNAL OUTPUT
Standard Operating Procedures Document
1
1
1
1
1
4
1
4
24
1
1
4
8
1
1
4

00 Picked up recording forms incinerator operation-east, incinerator operation-west and incinerator operation No. 2.

00 Recorded following data for east and west furnaces from Honeywell control console instruments and recorders:
Temperature - hearths 1 thru 5
Temperature - scrubbers in and out
Temperature - cooling air
Furnace draft
Gas meter

03

03 Recorded burner settings

04

05 Recorded filter cake accumulative reading and recorded hourly tons per hour subtraction.

06

07 Inspected furnace flame both furnaces - found insufficient burning east furnace.

07

07 Increased gas flow slowly.

09

10 Checked furnace shaft oilers.

10 Fills oil reservoir

13 Recorded psi water to scrubber precooler.

14 Recorded induced draft limit switch temperature.

14 Greased exhaust fan bearings on scrubber.

17 Checked conveyor belt.

17 Checked conveyor belt.

18 Recorded induced blowers fan amps.

19 Recorded induced draft spray wash psi.

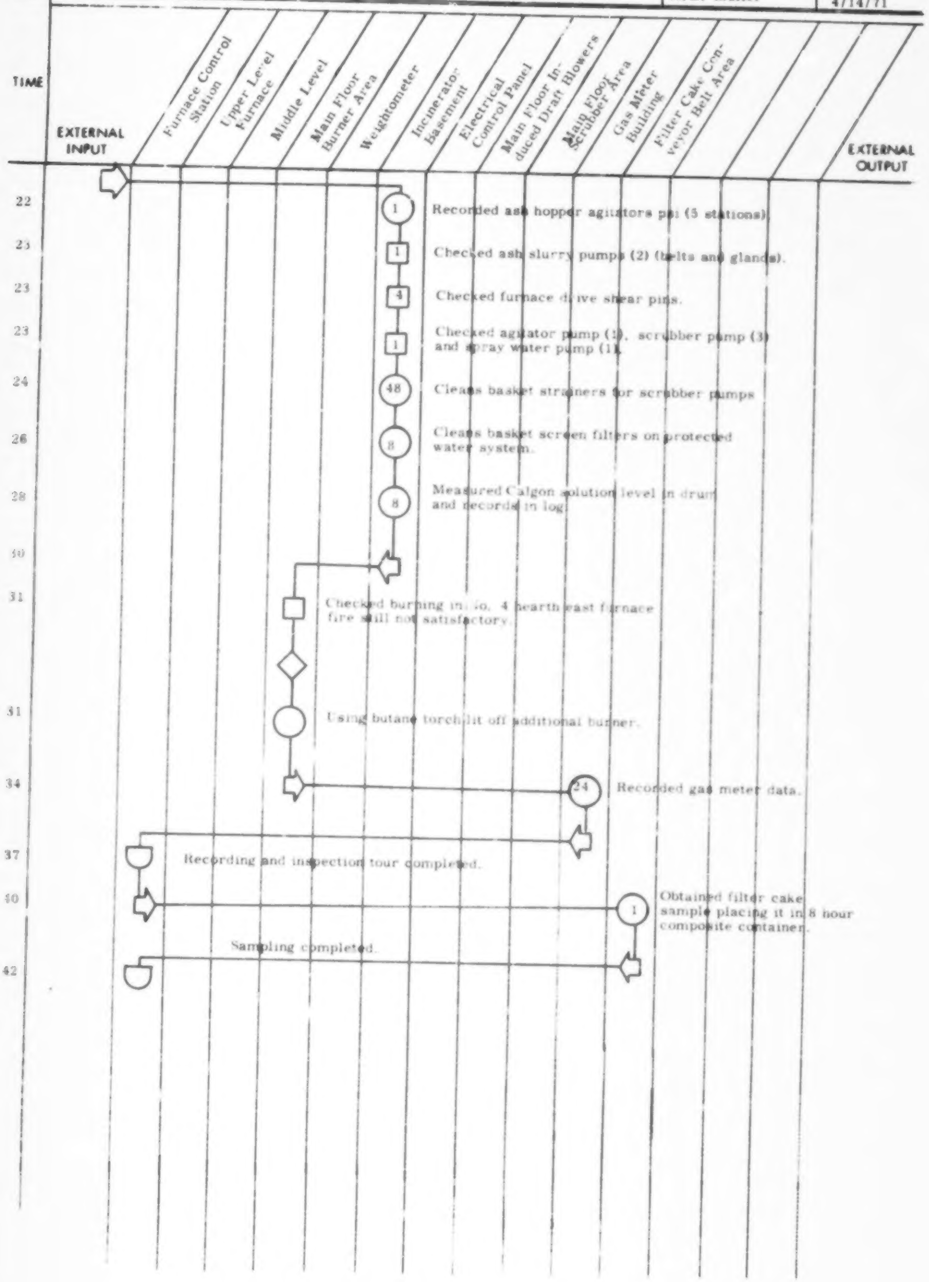
19 Recorded scrubber supply psi.

20

21 Checked ash hearths.

21 Checked ash chute.

SYSTEM Furnace Operator - Operations	PROJECT TITLE Application of Industrial Engineering Techniques	STAGE NO. -	SHEET NO. 2 of 2
USE OF WORKSHEET Jim Wezell - Flint Sewage Treatment Plant		PREPARED BY R. E. Muller	DATE 4/14/71


TIME
EXTERNAL INPUT
Furnace Control Station
Upper Level Furnace
Middle Level
Main Floor Burner Area
Weightometer
Incinerator Basement
Electrical Control Panel
Main Floor Induced Draft Blowers
Main Floor Scrubber Area
Gas Meter Building
Filter Cake Conveyor Belt Area
EXTERNAL OUTPUT
1
1
4
1
48
8
8
24
1

22 Recorded ash hopper agitators psi (5 stations).

23 Checked ash slurry pumps (2) (belts and glands).

23 Checked furnace drive shear pins.

23 Checked agitator pump (1), scrubber pump (3) and spray water pump (1).

24 Cleans basket strainers for scrubber pumps

26 Cleans basket screen filters on protected water system.

28 Measured Calgon solution level in drum and records in log.

30

31 Checked burning in No. 4 hearth east furnace fire still not satisfactory.

31 Using butane torch lit off additional burner.

34 Recorded gas meter data.

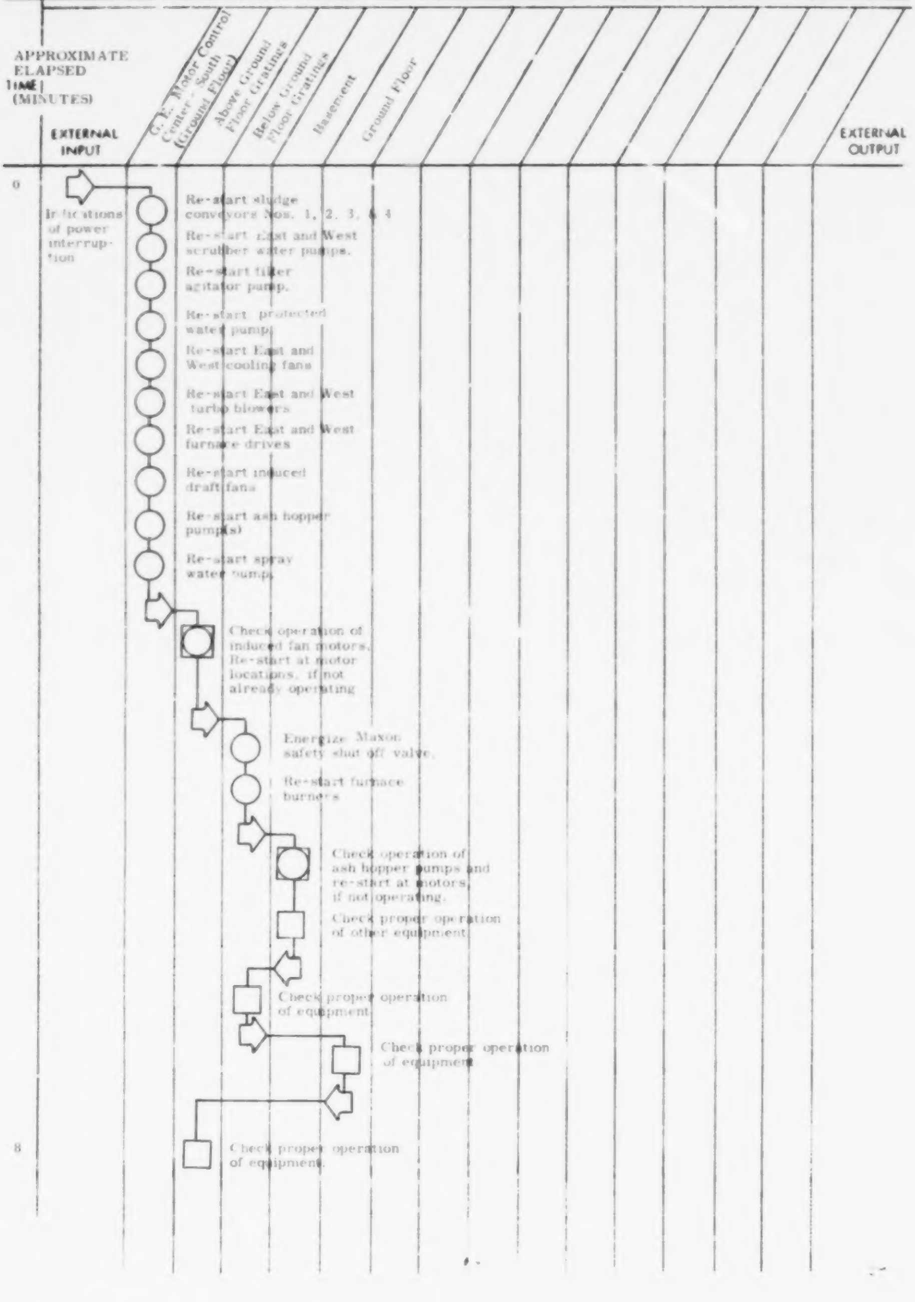
37 Recording and inspection tour completed.

40 Obtained filter cake sample placing it in 8 hour composite container.

Sampling completed.

42

SYSTEM Wastewater Treatment Plant, Flint, Mich. Incinerators and Associated Equipment	**PROJECT TITLE** Application of I. E. Techniques to Conventional and Advanced Wastewater Treatment Systems	**STAGE NO.** -	**SHEET NO.** 1
USE OF WORKSHEET Equipment Re-starting Procedures Furnace Operator after Elec. Power Interruption		**PREPARED BY** G. Calnan	**DATE** 5/12/71


APPROXIMATE ELAPSED TIME (MINUTES)
EXTERNAL INPUT
G. E. Motor Control Center - South (Ground Floor)
Above Ground Floor Gratings
Below Ground Floor Gratings
Basement
Ground Floor
EXTERNAL OUTPUT
0
8

Indications of power interruption

Re-start sludge conveyors Nos. 1, 2, 3, & 4

Re-start East and West scrubber water pumps.

Re-start filter agitator pump.

Re-start protected water pump.

Re-start East and West cooling fans

Re-start East and West turbo blowers

Re-start East and West furnace drives

Re-start induced draft fans

Re-start ash hopper pump(s)

Re-start spray water pump.

Check operation of induced fan motors. Re-start at motor locations, if not already operating

Energize Maxon safety shut off valve.

Re-start furnace burners

Check operation of ash hopper pumps and re-start at motors, if not operating.

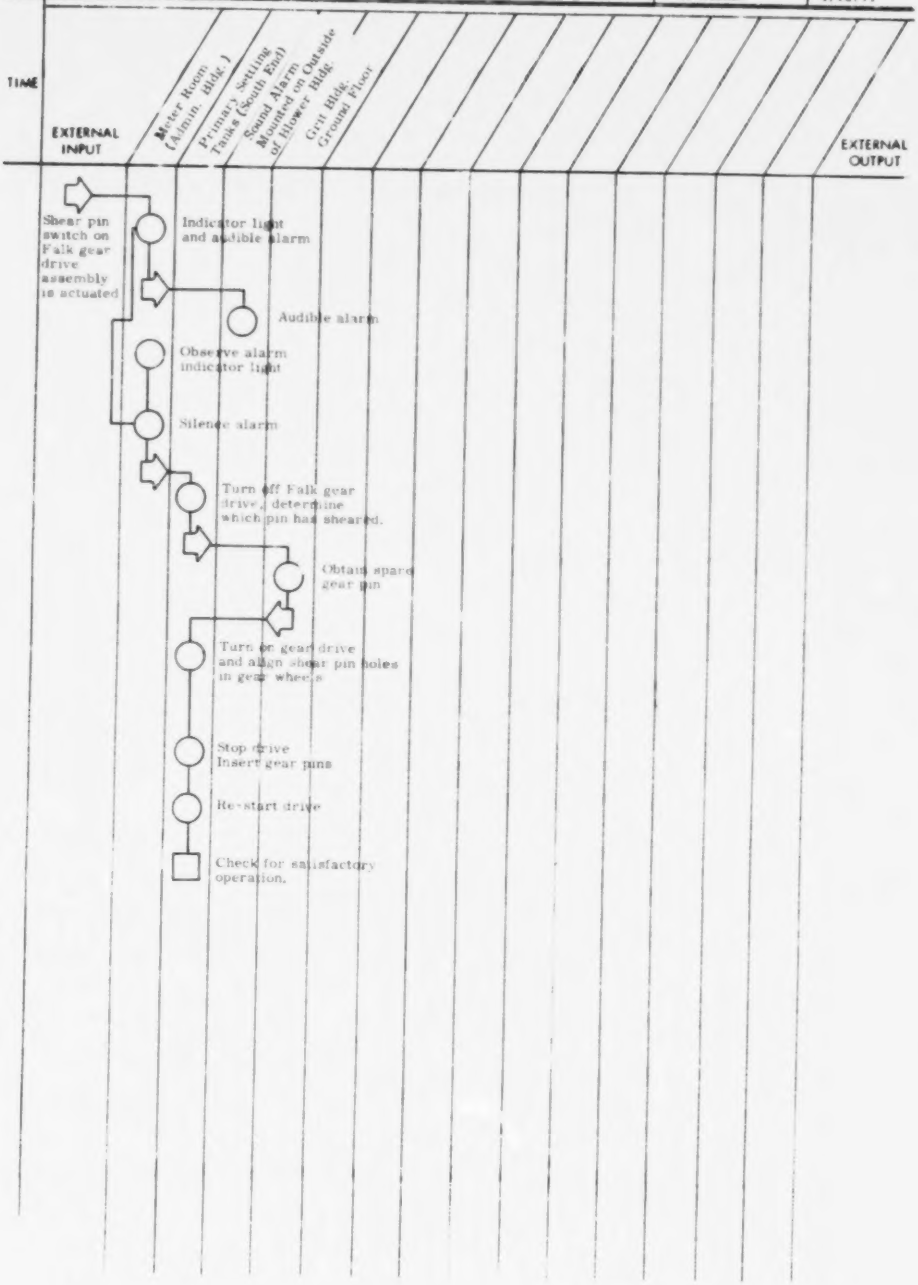
Check proper operation of other equipment.

Check proper operation of equipment.

Check proper operation of equipment.

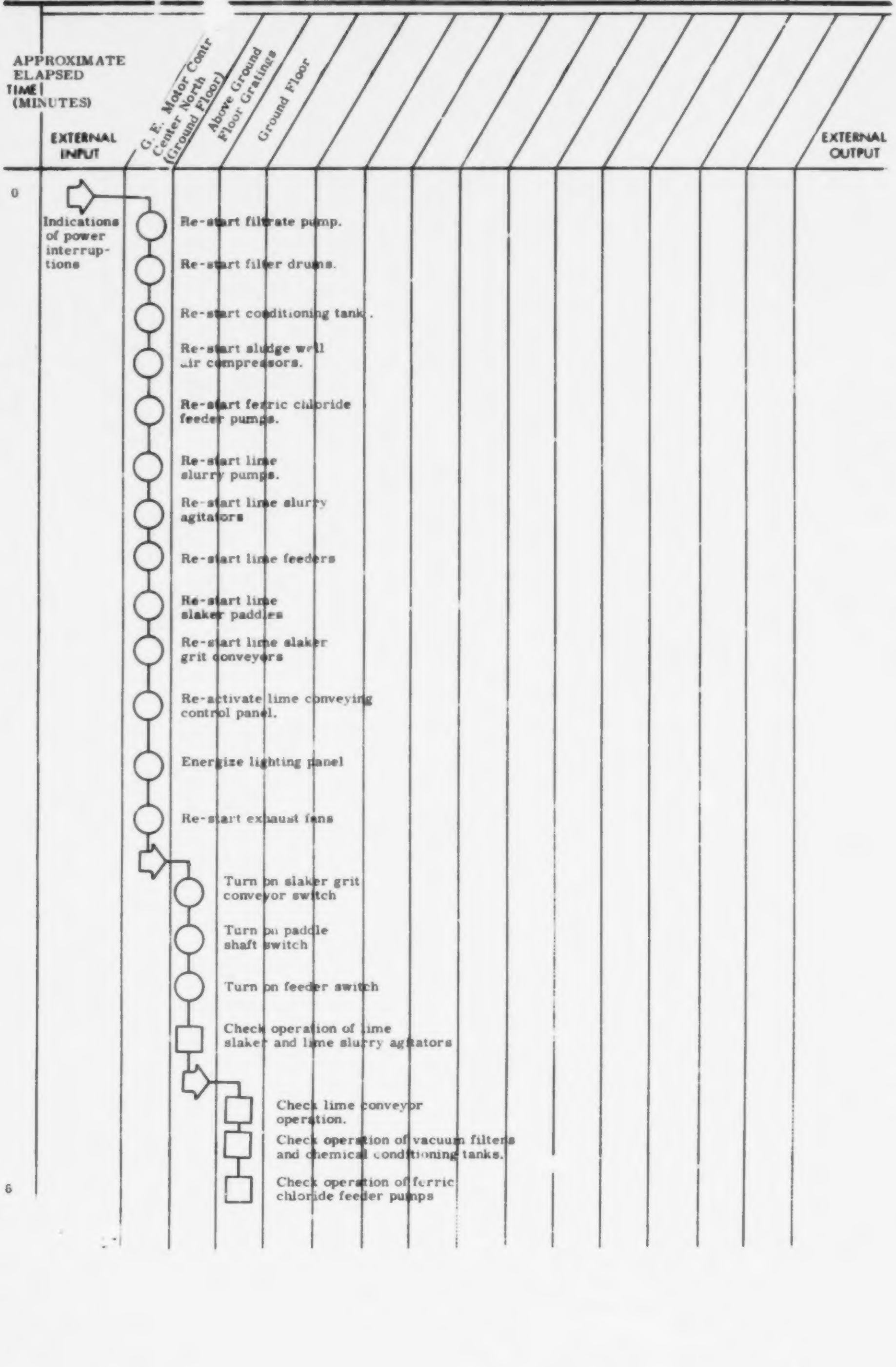
Check proper operation of equipment.

SYSTEM Wastewater Treatment Plant, Flint, Mich. Primary Subsystem Clarifier Scum-Sludge Flights	**PROJECT TITLE** Application of I. E. Techniques to Conventional and Advanced Wastewater Treatment Systems	**STAGE NO.**	**SHEET NO.** 1
USE OF WORKSHEET Procedures followed by foreman/ primary operator when primary tank alarm sounds		**PREPARED BY** G. Calnan	**DATE** 4/12/71

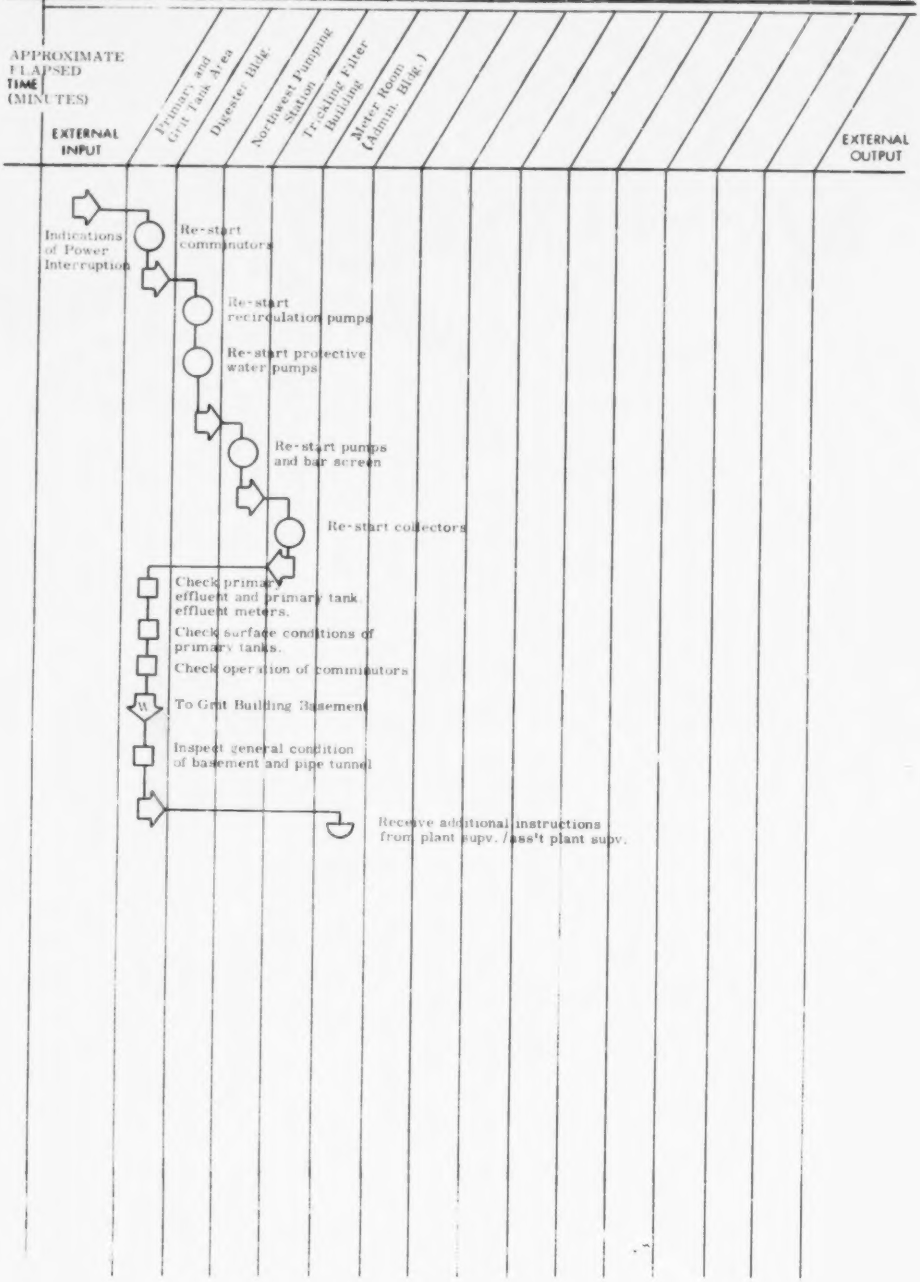


TIME
EXTERNAL INPUT
Meter Room (Admin. Bldg.)
Primary Settling Tanks (South End)
Sound Alarm Mounted on Outside of Blower Bldg.
Grit Bldg. Ground Floor
EXTERNAL OUTPUT
Shear pin switch on Falk gear drive assembly is actuated
Indicator light and audible alarm
Audible alarm
Observe alarm indicator light
Silence alarm
Turn off Falk gear drive, determine which pin has sheared.
Obtain spare gear pin
Turn on gear drive and align shear pin holes in gear wheels
Stop drive
Insert gear pins
Re-start drive
Check for satisfactory operation.

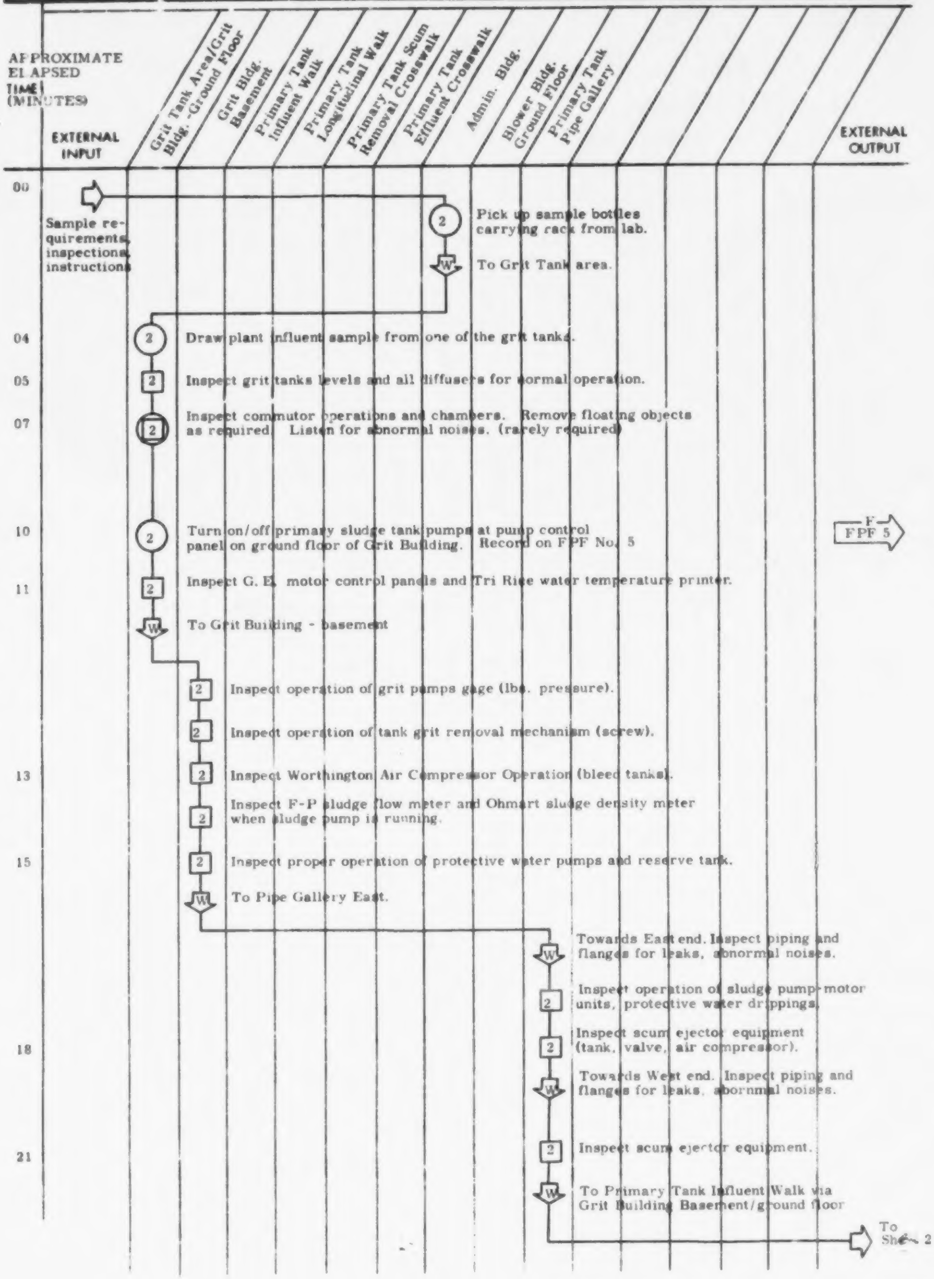
SYSTEM Wastewater Treatment Plant, Flint, Mich. Vacuum Filters and Associated Equipment	PROJECT TITLE Application of I. E. Techniques to Conventional and Advanced Wastewater Treatment Systems	STAGE NO.	SHEET NO. 1
USE OF WORKSHEET Equipment Re-starting Procedures Filter Operator after Elec. Power Interruption		PREPARED BY G. Calnan	DATE 5/12/71


APPROXIMATE ELAPSED TIME (MINUTES)
EXTERNAL INPUT
G. E. Motor Contr Center North (Ground Floor)
Above Ground Floor Gratings
Ground Floor
EXTERNAL OUTPUT
0
Indications of power interruptions
Re-start filtrate pump.
Re-start filter drums.
Re-start conditioning tanks.
Re-start sludge well air compressors.
Re-start ferric chloride feeder pumps.
Re-start lime slurry pumps.
Re-start lime slurry agitators
Re-start lime feeders
Re-start lime slaker paddles
Re-start lime slaker grit conveyors
Re-activate lime conveying control panel.
Energize lighting panel
Re-start exhaust fans
Turn on slaker grit conveyor switch
Turn on paddle shaft switch
Turn on feeder switch
Check operation of lime slaker and lime slurry agitators
Check lime conveyor operation.
Check operation of vacuum filters and chemical conditioning tanks.
Check operation of ferric chloride feeder pumps
6

SYSTEM Wastewater Treatment Plant, Flint, Mich. Primary Equipment/Final Tank Collectors	**PROJECT TITLE** Application of I. E. Techniques to Conventional and Advanced Wastewater Treatment Systems	**STAGE NO.**	**SHEET NO.** 1
USE OF WORKSHEET Equipment re-starting procedures by primary operator after elec. Power interruption		**PREPARED BY** G. Calnan	**DATE** 5/11/71


APPROXIMATE ELAPSED TIME (MINUTES)
EXTERNAL INPUT
Primary and Grit Tank Area
Digester Bldg.
Northwest Pumping Station
Trickling Filter Building
Meter Room (Admin. Bldg.)
EXTERNAL OUTPUT
Indications of Power Interruption
Re-start comminutors
Re-start recirculation pumps
Re-start protective water pumps
Re-start pumps and bar screen
Re-start collectors
Check primary effluent and primary tank effluent meters.
Check surface conditions of primary tanks.
Check operation of comminutors
W
To Grit Building Basement
Inspect general condition of basement and pipe tunnel
Receive additional instructions from plant supv./ass't plant supv.

SYSTEM Flint Wastewater Treatment Plant	PROJECT TITLE Application of I. E. Techniques to Conventional and Advanced Wastewater Treatment Systems	STAGE NO. -	SHEET NO. 1 of 2
USE OF WORKSHEET Describe operations performed by primary operator during two-hourly inspections		PREPARED BY G. Calnan	DATE 4/14/71


APPROXIMATE ELAPSED TIME (MINUTES)
EXTERNAL INPUT
Grit Tank Area/Grit Bldg. -Ground Floor
Grit Bldg. Basement
Primary Tank Influent Walk
Primary Tank Longitudinal Walk
Primary Tank Scum Removal Crosswalk
Primary Tank Effluent Crosswalk
Admin. Bldg.
Blower Bldg. Ground Floor
Primary Tank Pipe Gallery
EXTERNAL OUTPUT
2
W
F FPF 5
To Sheet 2

00 Sample requirements, inspections, instructions

Pick up sample bottles carrying rack from lab.

To Grit Tank area.

04 Draw plant influent sample from one of the grit tanks.

05 Inspect grit tanks levels and all diffusers for normal operation.

07 Inspect commutor operations and chambers. Remove floating objects as required. Listen for abnormal noises. (rarely required)

10 Turn on/off primary sludge tank pumps at pump control panel on ground floor of Grit Building. Record on FPF No. 5

11 Inspect G. E. motor control panels and Tri Rite water temperature printer.

To Grit Building - basement

Inspect operation of grit pumps gage (lbs. pressure).

Inspect operation of tank grit removal mechanism (screw).

13 Inspect Worthington Air Compressor Operation (bleed tanks).

Inspect F-P sludge flow meter and Ohmart sludge density meter when sludge pump is running.

15 Inspect proper operation of protective water pumps and reserve tank.

To Pipe Gallery East.

Towards East end. Inspect piping and flanges for leaks, abnormal noises.

Inspect operation of sludge pump-motor units, protective water drippings.

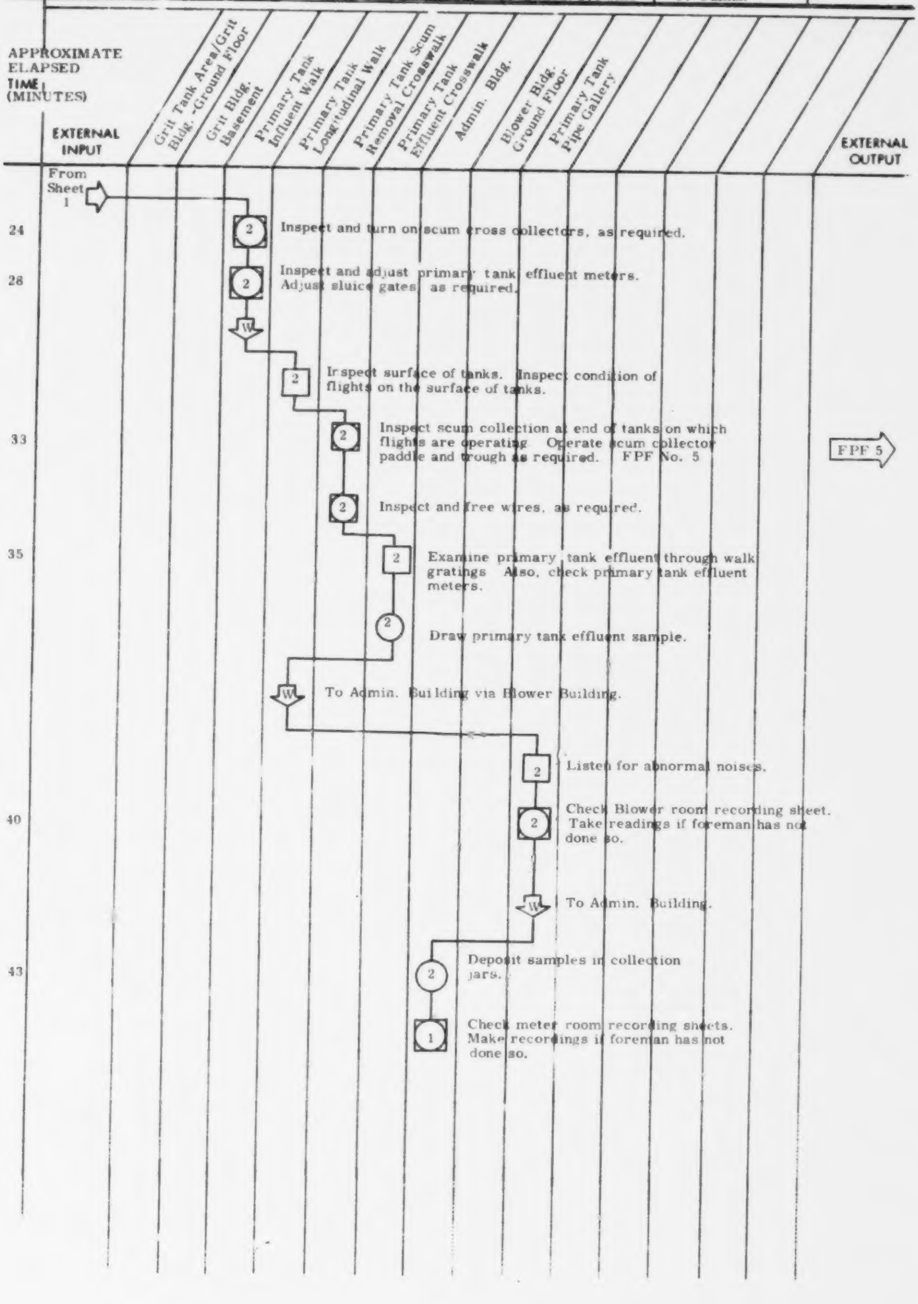
18 Inspect scum ejector equipment (tank, valve, air compressor).

Towards West end. Inspect piping and flanges for leaks, abnormal noises.

21 Inspect scum ejector equipment.

To Primary Tank Influent Walk via Grit Building Basement/ground floor

SYSTEM Flint Wastewater Treatment Plant **USE OF WORKSHEET** Describe operations performed by Primary Operator during two-hourly inspections	**PROJECT TITLE** Application of I.E. Techniques to Conventional and Advanced Wastewater Treatment Systems	**STAGE NO** - **PREPARED BY** G. Calnan	**SHEET NO.** 2 of 2 **DATE** 4/16/71


APPROXIMATE ELAPSED TIME (MINUTES)
EXTERNAL INPUT
Grit Tank Area/Grit Bldg.-Ground Floor
Grit Bldg. Basement
Primary Tank Influent Walk
Primary Tank Longitudinal Walk
Primary Tank Scum Removal Crosswalk
Primary Tank Effluent Crosswalk
Admin. Bldg.
Blower Bldg. Ground Floor
Primary Tank Pipe Gallery
EXTERNAL OUTPUT
From Sheet 1
2
W
1
FPF 5

24 Inspect and turn on scum cross collectors, as required.

28 Inspect and adjust primary tank effluent meters. Adjust sluice gates as required.

Inspect surface of tanks. Inspect condition of flights on the surface of tanks.

33 Inspect scum collection at end of tanks on which flights are operating. Operate scum collector paddle and trough as required. FPF No. 5

Inspect and free wires, as required.

35 Examine primary tank effluent through walk gratings. Also, check primary tank effluent meters.

Draw primary tank effluent sample.

To Admin. Building via Blower Building.

Listen for abnormal noises.

40 Check Blower room recording sheet. Take readings if foreman has not done so.

To Admin. Building.

43 Deposit samples in collection jars.

Check meter room recording sheets. Make recordings if foreman has not done so.

APPENDIX F

OPERATIONAL/MAINTENANCE TASK MATRICES
SEWAGE TREATMENT PLANT,
FLINT, MICHIGAN

SUBSYSTEM PRIMARY

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				UTILITIES OPERATOR		
				HIGH	MED	LOW
INSPECT AND RECORD						
Inspect grit tank levels and check air diffusers for normal operation	Grit Tank Area	Every 2 hours	34 Minutes			X
Check comminutor operation	Comminutor Channel Area	" " "				X
Inspect Motor Control Panel	Grit Bldg. - Main Floor	" " "				X
Check influent temperature recorder	Grit Bldg. - Main Floor	" " "				X
Check operation of grit pumps and inspect pressure gage	Grit Bldg. - Basement	" " "				X
Check operation of grit removal mechanism	Grit Bldg. - Basement	" " "				X
Check operation of air compressor	Grit Bldg. - Basement	" " "				X
Check operation of raw sewage pumps	Pumping Station	" " "				X
Check operation of mechanical bar screen rake	" "	" " "				X
Check raw sewage flow meter and recorder	" "	" " "				X
Inspect sludge flow meter and sludge density meter	Grit Bldg. - Basement	" " "				X
Check operation of protective water pump and inspect reserve tank	Grit Bldg. - Basement	" " "				X
Inspect piping and flanges for leaks	Primary - Pipe Gallery	" " "				X
Check operation of sludge pumps	Primary - Pipe Gallery	" " "				X
Check operation of scum ejector equipment (tank, valve, and air compressor)	Primary - Pipe Gallery	" " "				X
Check operation of primary effluent pumps and record inlet and outlet pressures	Aeration - Pipe gallery	" " "				X

Sheet 1 of 6

SUBSYSTEM PRIMARY

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				UTILITIES OPERATOR		
				HIGH	MED	LOW
INSPECT AND RECORD - (continued)						
Check scum cross collectors	Primary Tank Area	Every 2 hours				X
Check primary effluent flow meters	" " "	" " "				X
Check scum and other floating items on surface of tank	" " "	" " "				X
Inspect operation of flights	" " "	" " "				X
Inspect weirs	" " "	" " "				X
Observe primary effluent characteristics	" " "	" " "			X	
Record depth of primary sludge	" " "	Daily	6 Minutes			X
Record operation time of sludge pumps	Motor Control Panel	As required	NAT*			X
Record operation time of grit pumps	" " "	" "				
SAMPLES						
Influent (24 hour composite)	Grit Tank Area	Every 2 hours	3 Minutes			X
Primary effluent (24 hour composite)	Primary Effluent Channel	" "				X
NORMAL OPERATIONS						
Start/stop sludge pumps	Motor Control Panel	Every 2 hours				
Bleed water from filter of air compressor	Grit Bldg. - Basement	" " "	4 Minutes		X	
Adjust scum cross collectors	Primary Tank Area	" " "			X	
Clean basket screen filters in protected water system	Grit Bldg. - Basement	Every 8 hours	2 Minutes		X	

*NAT - No Appreciable Time.

Sheet 2 of 6

SUBSYSTEM PRIMARY

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				UTILITIES OPERATOR		
				HIGH	MED	LOW
NORMAL OPERATIONS - (continued)						
Start/stop raw sewage pumps	Pumping Station	As required	Approx. 20 Mins. Daily		X	
Start/stop mechanical bar screen rake	" "	" "			X	
Remove container of debris from rake and clean-up area	" "	" "				X
Remove floating objects from comminutor channel	Comminutor Channel	" "				X
Adjust primary tank sluice gates	Primary Tank Area	" "	Approx. 12 Mins. Daily			X
Operate scum collector paddle	" " "	" "				X
Free weirs of debris	" " "	" "				
Start/stop grit screws	Motor Control Panel	" "	Unknown		X	
Start/stop grit pumps	" " "	" "				
NON-ROUTINE OPERATIONS						
Power Interruption						
Restart comminutors	" " "	Average of 4 times per year	Approx. 15 Mins.		X	
Restart settled sewage pumps	Blower Bldg.					
Restart raw sewage pumps	Pumping Station					
Restart mechanical Bar Screen Rake	" "					
Observe primary effluent characteristics	Primary Tank Area					
Observe effluent meters	" " "					
Observe surface conditions of primary tank	" " "					
Check operation of comminutors	Comminutor Channel Area					
Inspect all equipment and piping in Grit Bldg., Basement, and Primary Pipe Gallery	Grit Bldg. - Basement					

SUBSYSTEM PRIMARY

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL UTILITIES OPERATOR HIGH	 MED	 LOW
NON-ROUTINE OPERATIONS - (continued)						
Shear Pin on Flights Shears					X	
Silence Shear Pin Alarm	Admin. Bldg. - Meter Room	Average of 6 times per year	Approx. 12 Mins.			
Stop flight gear drive motor	Primary Tank Area					
Inspect flights to determine where shear pin has sheared	Primary Tank Area					
Obtain spare shear pin	Grit Bldg. - Main Floor					
Start flight gear drive motor and align shear pin holes in gear wheels	Primary Tank Area					
Stop flight gear drive motor	" " "					
Insert new gear shear pin(s)	" " "					
Start flight gear drive motors and check for proper operation	" " "					
PREVENTIVE MAINTENANCE						
Replenish oil in oilers of sludge pumps	Grit Bldg. - Basement	Every 2 hours or as needed	- 3 Mins.			X
Replenish oil in oilers of air compressor	" " "	Every 8 hours or as needed	- 3 Mins.			X
Tighten packing glands of raw sewage pumps	Pumping Station	As required	- 2 Mins.		X	

SUBSYSTEM PRIMARY

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				MAINTENANCE MECHANIC		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE - (continued)						
Grease and check oil in comminutors	Comminutor Channel Area	Weekly	4 Hours			
Check oil in gear case of flight gear drives	Primary Tank Area	"				
Check oil level in oiler of screen ejectors	Primary Pipe Gallery	"				
Check oil, packing and clean strainers of sludge pumps	Grit Bldg. - Basement	"				
Check oil level and drain water from air compressors	" " "	"				
Check oil, packing, and clean strainers of grit pumps	" " "	"				
Grease and check grit screw mechanism	" " "	"				
Check protected water system	" " "	"				
Check venturi meter	" " "	"				
Check swing fuser joints	Primary Tank Area	"				
Check shear pins on flight drive gears	" " "	"				
Check effluent meters	" "	"				
Grease and check raw sewage pumps	Pumping Station	Monthly	↓			
Check oil level and check operation of bar screen rake mechanism	" "	"				
Lubricate grit screw drive	Grit Bldg. - Basement	"				
Clean strainer and belt on grit pump	" " "	"				
Clean and test air compressor	" " "	"				

Sheet 5 of 6

SUBSYSTEM PRIMARY

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				MAINTENANCE MECHANIC		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE - (continued)						
Clean strainers and belts of sludge pumps	Grit Bldg. - Basement	Monthly	5 Hours			
Clean air filter and oil scum ejectors	Primary - Pipe Gallery	"				
Lubricate flight drive mechanisms	" " "	"				
Check operation of comminutors	Comminutor Channel Area	"				
				MAINTENANCE ELECTRICIAN		
Clean motor control panels	Grit Bldg. - Main Floor	Monthly	4 Hours			
Check, clean and adjust meters and recorders	Grit Bldg., Primary	"				
Check, lubricate, clean and adjust motors: Raw Sewage Pumps Mechanical Bar Screen Rake Sludge Pumps Air Compressors Flight Gear Drive Comminutors Grit Pump Grit Screw	Tank Area, Pumping Station	"				

Sheet 6 of 6

SUBSYSTEM ACTIVATED SLUDGE

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL ACTIVATED-SLUDGE OPERATOR HIGH	 MED	 LOW
INSPECT AND RECORD						
Record following meter readings: Total raw sewage rate (MGD) Settled sewage to aeration tanks Return sludge to aeration tanks	Admin. Bldg.-Meter Room	Hourly	- 2 Mins.		X	
Record weather data	Admin. Bldg. Area	Every 2 hours	51 Mins.		X	
Check operation of return sludge pumps	Pipe Gallery	" " "			X	
Check operation of waste sludge pumps	" "	" " "			X	
Inspect equipment & piping in pipe gallery for abnormal noise or leaks	" "	" " "			X	
Check operation of high pressure final effluent pumps and record inlet and outlet pressures	Pipe Gallery	" " "			X	
Check level of primary effluent on depthmeter	" "	" " "			X	
Inspect protected water system	Blower Bldg. - Basement	" " "			X	
Check volume of blower air on recorder	" " "	" " "			X	
Check operation of instrument air compressors	" " "	" " "			X	
Check operation of travelling water screens	Aeration Tank Area	" " "			X	
Check surface conditions and operation of final clarifier	Final Clarifier Area	" " "			X	
Inspect blower operation and record following for each operating blower: Exciter bearing temp. Drive and bearing temp.	Blower Bldg.	" " "			X	

Sheet 1 of 6

SUBSYSTEM ACTIVATED SLUDGE

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL ACTIVATED-SLUDGE OPERATOR		
				HIGH	MED	LOW
INSPECT AND RECORD - (continued)						
Highest thermo temp.						
D. C. amps						
Air temp and pressure						
Bearing temps. (each end and center)						
Oil pressure						
Oil inlet and outlet temps.						
AC amps.						
Internal guide vane setting						
Kilowatts						
SAMPLES						
Suspended solids -- mixed liquor	Aeration Tanks	Every 2 hours	15 Mins.			X
BOD -- mixed liquor	" "	" " "				X
Suspended solids -- final effluent	Final Effluent Channel	" " "				X
BOD -- final effluent	" " "	" " "				X
Dissolved oxygen -- mixed liquor	Aeration Tanks	Every 4 hours	10 Mins.			X
Dissolved oxygen -- final effluent	Final Effluent Channel	" " "				X
Dissolved oxygen -- river	River	" " "				X
BOD & suspended solids -- return sludge	Aeration Bldg.	" " "				X
NORMAL OPERATIONS						
Adjust controls on console to regulate return sludge to aeration tanks	Admin. Bldg. - Meter Rm.	Hourly or as required	- 3 Mins.	X		

Sheet 2 of 6

SUBSYSTEM ACTIVATED SLUDGE

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL ACTIVATED - SLUDGE OPERATOR HIGH	SKILL ACTIVATED - SLUDGE OPERATOR MED	SKILL ACTIVATED - SLUDGE OPERATOR LOW
NORMAL OPERATIONS (continued)						
Perform laboratory analysis for suspended solids	Aeration Bldg. - Lab	Every 2 hours	30 Mins.	X		
Bleed moisture from instrument air compressor and H.P. air compressor	Blower Bldg. - Basement	" " "				X
Perform laboratory analysis for dissolved oxygen	Aeration Bldg. - Lab	Every 4 hours	- 5 Mins.	X		
Clean basket screen filters in protected water system	Blower Bldg. - Basement	Every 8 hours	- 2 Mins.			X
Start/stop pumps (waste sludge, return sludge, protected water, effluent, mixed liquor, etc.)	Pipe Gallery	As required	Comprises an average of 15 mins. every 8 hours		X	
Open/close valves	Pipe Gallery	" "			X	
Open/close sluice gates	Mixed Liquor Channel					X
Clear final clarifiers of surface scum	Final clarifier	" "				X
Start/stop blowers	Blower Bldg.	" "		X		
Adjust blower vane settings	" "	" "		X		
NON-ROUTINE OPERATIONS						
Power Interruption				X		
Stop stand-by blower and restart in-service blower	" "	Average of 4 times per year	15 Mins.			
Check blower motor gages for proper readings	" "					
Re-energize following units:	Aeration Bldg.-Control Panel					
Primary effluent pumps	" " "					
Travelling water screens	" " "					

Sheet 3 of 6

SUBSYSTEM ACTIVATED SLUDGE

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				ACTIVATED - SLUDGE OPERATOR		
				HIGH	MED	LOW
NON-ROUTINE OPERATIONS - Power Interruption (continued)						
H.P. final effluent pumps	Aeration Bldg.-Control Panel					
Spray water pumps	" " " "					
Return sludge pumps	" " " "					
Waste sludge pumps	" " " "					
Protected water pumps	Blower Bldg. - Basement					
Instrument air compressor	" " "					
Check air flow meter for proper reading	" " "					
Visually check operation of above units						
PREVENTIVE MAINTENANCE						
Adjust packing glands on all pumps (spray water, return sludge, waste sludge, and effluent)	--	As required	2 Mins.		X	
Check and clean instrument air filters in control consoles	Admin. Bldg. - Meter Room	Weekly	6 Hours	MAINTENANCE MECHANIC		
Clean strainers and check oil level of blowers	Blower Bldg.	"				
Check oil level in blower motors	" "	"				
Clean and replenish oil in air dryer	" " - Basement	"				
Check oil level and drain moisture from instrument air compressor and H.P. air compressor	" " "	"				
Check packing glands on all pumps, adjust as necessary (spray water, return sludge, waste sludge and effluent)	Pipe Gallery	"				
Clean strainers in pressure reducing valves of return sludge and waste sludge pumps	" "	"				
Check oil level in oiler of scum ejector	" "	"				

Sheet 4 of 6

SUBSYSTEM ACTIVATED SLUDGE

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				MAINTENANCE MECHANIC		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE (continued)						
Lubricate and check oil level of gear mechanism of final clarifiers	Final Clarifiers	Weekly	↑			
Blow down travelling water screen controllers	Aeration Tank Area	"				
Swing diffuser joints, replace diffusers and clean diffuser	" " "	"				
Exchange moisture traps in consoles and clean	Admin. Bldg.-Meter Room	Monthly	2 Hours			
Clean screens and moisture traps in blowers	Blower Bldg.	"				
Clean, test safety valves and replace air cleaners of instrument air compressor and H.P. air compressor	Blower Bldg. - Basement	"				
Check operation of protected water system	" " "	"				
Clean, check packing, lubricate and adjust belts of pumps (effluent, waste sludge, return sludge, spray water)	Pipe Gallery	"				
Clean scum ejectors	" "	"				
Lubricate, check oil level and adjust travelling water screens	Aeration Tank Area	"				
Lubricate and check operation of final clarifier mechanism	Final Clarifier	"				

Sheet 5 of 6

SUBSYSTEM ACTIVATED SLUDGE

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				MAINTENANCE ELECTRICIAN		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE - (continued)						
- Clean motor control panels	Blower Bldg.	Monthly	5 Hours			
- Check, lubricate, clean and adjust following motors: Blowers Instrument air compressors H.P. air compressors Effluent pumps Spray water pumps Return sludge pumps Waste sludge pumps Travelling water screen	" "	"				
- Check, clean, adjust meters and recorders of control consoles. Replenish ink in recorder needles	Admin. Bldg.-Meter Room	Quarterly	- 1 1/2 Hrs			

Sheey 6 of 6

SUBSYSTEM TRICKLING FILTER

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL UTILITIES OPERATOR HIGH	MED	LOW
INSPECT AND RECORD						
Record settled sewage flow to T. F. (MGD)	Admin. Bldg.-Meter Room	Hourly	- NAT*			X
Check operation of settled sewage pumps	Blower Bldg. - Basement	Every 2 hours	4 Mins.			X
Check operation of filter spray nozzles	Filter Field	" " "				
Check surface conditions and operation of final clarifiers	Final Clarifier	" " "				
Check operation of humus sludge pumps	T. F. Bldg.	" " "			X	
SAMPLES						
Suspended solids -- final effluent	Final Effluent Channel	" " "	3 Mins.		X	
BOD -- final effluent	" " "	" " "				
Dissolved oxygen -- final effluent	" " "	Every 4 hours	- 2 Mins.		X	
NORMAL OPERATIONS						
Perform laboratory analysis for dissolved oxygen	T. F. Bldg.	Every 4 hours	- 10 Mins.	X		
Start/stop humus sludge pumps	" " "	As required	Comprises an average of 2 hours daily			
Open/close valves	" " "	" "			X	
Start/stop protected water pumps	" " "	" "				X
Start/stop settled sewage pumps	Blower Bldg.	" "			X	
Replace filter spray nozzles and clean nozzles	Filter Field	" "				X
Clear final clarifiers of surface scum	Final clarifiers	" "				X

*NAT = No Appreciable Time.

Sheet 1 of 2

SUBSYSTEM TRICKLING FILTER

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				UTILITIES OPERATOR		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE						
Adjust packing glands on pumps	T. F. Bldg. Blower Bldg. - Basement	As required	- 2 Mins.		X	
				MAINTENANCE MECHANIC		
Inspect, replace and clean filter spray nozzles	Filter Field	Weekly	Approx. 20 Mins.			
Inspect filter bed	" "	"				
Check, lubricate, and adjust packing glands and belt of humus sludge pump	T. F. Bldg.	Monthly	1/2 Hr.			
Check operation of protected water system	" " "	"				
Check, lubricate final settling tank mechanism	Final Clarifiers	"				
				MAINTENANCE ELECTRICIAN		
Clean motor control panels	T. F. Bldg. Blower Bldg.	"	1 1/4 Hrs.			
Check, lubricate, clean and adjust motors: Final Clarifiers Humus Sludge Pumps Protected Water Pumps Settled Sewage Pumps		"				

Sheet 2 of 2

SUBSYSTEM AIR FLOTATION

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL SLUDGE-CONTROL OPERATOR HIGH	 MED	 LOW
INSPECT AND RECORD						
Check motor control panel for proper settings	Thickener Bldg.	Every 2 hours	9 Mins.		X	
Check operation of instrument air compressor	" "	" " "			X	
Check sludge flow meter	Thickener Bldg.-Basement	" " "			X	
Check operation of flotation air compressor	" " "	" " "			X	
Check operation of grit removal pumps	" "	" " "			X	
Check operation of sludge pumps	" " "	" " "				
Check operation of protected water system	" " "	" " "				
Check sludge characteristics at input end of thickening tanks	Thickener Tanks	" " "			X	
Check characteristics of sludge on surface of thickening tanks	" "	" " "			X	
Inspect operation of flights	" "	" " "			X	
Check characteristics of subnatant	" "	" " "			X	
Inspect magnetrol switches	Thickener Bldg.-Basement	Every 8 hours	- NAT*		X	
SAMPLES						
Thickened sludge (24 hour composite)	Thickener Tanks	Every 2 hours	3 Mins.			X
Thickener subnatant (24 hour composite)	" "	" " "				X

*NAT = No Appreciable Time.

Sheet 1 of 5

SUBSYSTEM AIR FLOTATION

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				SLUDGE-CONTROL OPERATOR		
				HIGH	MED	LOW
NORMAL OPERATIONS						
Bleed moisture from air compressors	Thickener Bldg.	Every 2 hours	5 Mins.		X	
Adjust automatic settings on time clocks for grit flights, sludge skimmer, sludge screw, and grit screw	Thickener Bldg.-Basement Motor Control Panel	" " " " " "				
Flush out magnetrol switch cylinders on air pressure tanks	Thickener Bldg.-Basement	Every 8 hours	12 Mins.			
Clean basket screen filters in protected water system	" " "	" " "			X	
Alternate protected water pumps	" " "	Daily				
Alternate air compressors	" " "	"	- 2 Mins.		X	
Start/stop pumps (grit, thickened sludge)	" " "	As required	Comprises 12 Mins. Daily			
Open/close valves	" " "	" "			X	
NON-ROUTINE OPERATIONS						
Power Interruption						
Restart air compressors (instrument and flotation)	Thickener Bldg. Thickener Bldg.-Basement	Average 4 times per year	- 2 Mins.		X	
PREVENTIVE MAINTENANCE						
- Replenish oil in oilers of sludge pumps	" " "	As required	8 Mins.		X	
- Replenish oil in oilers of air compressors	" " "	" "			X	
- Tighten packing glands of pumps (grit, sludge)	" " "	" "			X	
- Replace shear pins on flights and skimmers	Thickener Tanks	" "			X	

Sheet 2 of 5

SUBSYSTEM AIR FLOTATION

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				MAINTENANCE MECHANIC		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE (continued)						
Check, lubricate, adjust belt, clean filters, and blow moisture of air compressor	Thickener Bldg.-Basement	Weekly	4 Hours			
Check, lubricate and tighten packing gland of grit screw mechanisms	" " "	"				
Check, lubricate and tighten packing gland of grit pumps	" " "	"				
Check oil level, adjust packing glands and lubricate flight and skimmer mechanisms	" " "	"				
Check oil level, adjust packing glands and lubricate sludge pumps	" " "	"				
Clean and check operation of magnetrol switch units	" " "	"				
Clean line of venturi meters	" " "	"				
Check, lubricate, adjust belt, clean filters, and blow moisture of instrument air compressor	Thickener Bldg.	"				
Check oil level, adjust packing glands, and lubricate protected water pumps	" "	"				
Check operation, replace shear pins, lubricate and adjust tension of skimmers	Thickener Tanks	"				
Lubricate drive chain and check oil level of grit screw mechanism	Thickener Bldg.-Basement	Monthly	↓			
Clean strainer of grit pump	" " "	"				

Sheet 3 of 5

SUBSYSTEM AIR FLOTATION

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL MAINTENANCE MECHANIC HIGH	 MED	 LOW
PREVENTIVE MAINTENANCE (continued)						
Clean and test safety valves of flotation air compressor	Thickener Bldg.-Basement	Monthly	2 Hours			
Check and replace filters and clean air dryer water trap of instrument air system	" " "	"				
Clean strainers of sludge pumps	" " "	"				
Lubricate and check oil level of flight mechanisms (bottom collectors)	" " "	"				
Clean and test safety valves of instrument air compressors	Thickener Bldg.	"				
Check oil level and lubricate drive units of skimmers	Thickener Tanks	"				
Check oil level of sludge screw drive	" "	"				
Lubricate screw drive chain	" "	"				
Check lubrication of skimmer hangers	" "	"				
				MAINTENANCE ELECTRICIAN		
Clean motor control panel	Thickener Bldg.	"	4 hours			
Check, clean, and adjust meters	" " Thickener Bldg.-Basement Thickener Tank Area	" " "				
Check, lubricate, clean, and adjust motors: Skimmer Flights (bottom collector) Thickened sludge pump		"				

Sheet 4 of 5

SUBSYSTEM AIR FLOTATION

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				MAINTENANCE ELECTRICIAN		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE (continued)						
Grit screw Grit pump Instrument air compressor Flotation air compressor Protected water pumps			↑			

Sheet 5 of 5

SUBSYSTEM DEWATERING SYSTEM

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL SLUDGE-FILTRATION OPERATOR HIGH		
				HIGH	MED	LOW
INSPECT AND RECORD						
Check sludge tank agitator air compressor and check level of oil in oilers	Sludge Pump Area	Hourly	23 Minutes			X
Observes scrapers in vacuum filter to ensure filter cake is being removed correctly	Vacuum Filter Area	Hourly			X	
Inspect $FECL_3$ day tank and record depth level and flow rate	$FECL_3$ Day Tank Area	Hourly				X
Check sludge in filter sump	Vacuum Filter Area	Hourly			X	
Check oil level in vacuum pumps	Vacuum Pump Area	Hourly				X
Inspect consistency of filter cake	Vacuum Filter Area	Hourly			X	
Inspect filter coil spray water	Vacuum Filter Area	Hourly				X
Record total tonnage of filter cake and tons per hour	Conveyor Belt Area	Hourly				X
Record seal water pressure on filters	Vacuum Filter Area	Hourly				X
Record filter vacuum gage readings	Vacuum Filter Area	Hourly				X
Inspect lime feeder equipment and record register, pounds/hour, pressure, torque, grit water flow rate and spray water flow rate	Lime Slaker Area	Hourly			X	
Inspect Sludge Pumps	Sludge Pump Area	Hourly			X	
Check level of oil in oilers of sludge pumps	Sludge Pump Area	Hourly				X
Records register reading on sludge pumps	Sludge Pump Area	Hourly				X
Check packing glands of filtrate pumps	Filtrate Pump Area	Hourly				X

Sheet 1 of 6

SUBSYSTEM DEWATERING SYSTEM

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				SLUDGE-FILTRATION OPERATOR		
				HIGH	MED	LOW
INSPECT AND RECORD (continued)						
Record motor setting of lime pumps	Lime Slaker Area	Hourly				X
Check level of oil in oilers for filter chains	Vacuum Filter Area	Every 8 hours	NAT*			X
Check level of lime in lime storage tank	Lime Storage Tank Area	Daily	4 Minutes			X
Record drum settings on filters	Vacuum Filter Area	When changed	NAT*			X
Record chemical conditioning tank settings	Chem. Cond. Tank Area.	When changed				X
SAMPLES						
Filtrate (24 hour composite)	Vacuum Pump Area	Every 2 hours	3 Minutes			X
Sludge (24 hour composite)	Sludge Pump Area	Every 4 hours	2 Minutes			X
$FECL_3$ sample for specific gravity test	$FECL_3$ Day Tank Area	Each time tank is filled and beginning of each shift	4 Minutes			X
NORMAL OPERATIONS						
Lubricate sludge pump plungers	Sludge Pump Area	Every 2 hours	8 Minutes			X
Transfer lime from storage tank to slakers	Lime Storage Tank Area	" " "				X
Perform specific gravity test of $FECL_3$	Filter Laboratory	Every 8 hours			X	

*NAT = No Appreciable Time.

Sheet 2 of 6

SUBSYSTEM DEWATERING SYSTEM

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				SLUDGE-FILTRATION OPERATOR		
				HIGH	MED	LOW
NORMAL OPERATIONS (continued)						
Fill $FECL_3$ Day Tank	$FECL_3$ Day Tank Area	Every 8 hours	33 Minutes		X	
Bleed water from filter of Sludge Tank Agitator air compressor	Sludge Pump Area	Every 8 hours				X
Prepare Daily Filtration Pumpage and Chemical Feed Log	Filter Laboratory	Daily (Midnight)	30 Minutes		X	
Energize and de-energize vacuum filter agitators	Vacuum Filter Area	As required	Comprises an average of 16 minutes every 4 hrs.			
Adjust filter coil spray water	Vacuum Filter Area	As required			X	
Adjust drum speed of vacuum filter	Vacuum Filter Area	As required			X	
Start, stop and regulate sludge pumps	Sludge Pump Area	As required			X	
Start, stop and regulate $FECL_3$ pumps	$FECL_3$ Tank Area	As required			X	
Start, stop and regulate lime slurry pumps	Lime Slurry Tank Area	As required			X	
NON-ROUTINE OPERATIONS						
Power Interruption						
Re-energize following equipment in sequence:		Average of 4 times per year	30 Minutes		X	
Lighting Panel	Motor Control Panel					
Lime Slurry Agitator	" " "					
Lime Slurry Pump	" " "					
$FECL_3$ Feeder Pump	" " "					
Sludge Tank Agitation Air Compressor	" " "					
Filtrate Pump	" " "					
Vacuum Filter Drum	" " "					
Conditioning Tank	" " "					

Sheet 3 of 6

SUBSYSTEM DEWATERING SYSTEM

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				SLUDGE-FILTRATION OPERATOR		
				HIGH	MED	LOW
NON-ROUTINE OPERATIONS (continued)						
Power Interruption (continued)						
Lime Slaker Grit Conveyor	Motor Control Panel				X	
Lime Slaker	" " "					
Lime Feeder	" " "					
Exhaust Fans	" " "					
Check operation of above equipment and adjust accordingly.						
Conveyor Pulley Stoppage						
De-energize following equipment in sequence:		Average of 8 times a year	Comprises an average of 50 minutes operator time.		X	
Filter drums	Motor Control Panel					
Conveyors	" " "					
Conveyor alarm	" " "					
Sludge pumps	" " "					
$FECL_3$ feeder pumps	" " "					
Lime slurry pump	" " "					
Lime conveyor	" " "					
Lime feeder	" " "					
Lime slaker paddle	" " "					
Lime slaker grit conveyor	" " "					
Conditioning tank	" " "					
Filtrate pump	" " "					
Assist Furnace Operator in corrective action and then energize following equipment in sequence:						
Conveyors						
Filter drums						
Remainder of equipment in reverse order as shown above.						

Sheet 4 of 6

SUBSYSTEM DEWATERING SYSTEM

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				SLUDGE-FILTRATION OPERATOR		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE						
Replenish oil in oilers of sludge pumps	Sludge Pump Area	Every 2 hours or as needed	3 Minutes			X
Replenish oil in oilers of sludge tank agitator air compressor	Sludge Pump Area	Every 8 hours or as needed	3 Minutes			X
Grease vacuum filter zerk fittings	Vacuum Filter Area	Daily	4 Minutes			X
Grease lime slurry pump zerk fittings	Slurry Pump Area	Daily				X
Replenish oil in vacuum pump	Vacuum Pump Area	As Required	5 Minutes (Daily)		X	
Replenish oil in oilers for filter chains	Vacuum Filter Area	As Required				
Tighten packing glands of filtrate pumps	Filtrate Pump Area	As Required				
				MAINTENANCE MECHANIC		
Check, lubricate and adjust lime conveying system	Lime Storage Tank Area	Weekly	5 1/2 Hrs.			
Check, lubricate and adjust lime slakers	Lime Slaker Area	Weekly				
Check and lubricate lime slurry pumps	Lime Slurry Tank Area	Weekly				
Check and lubricate FECL$_3$ solution pumps	FECL$_3$ Day Tank Area	Weekly				
Lubricate FECL$_3$ Transfer Pump	FECL$_3$ Day Tank Area	Weekly				
Check, lubricate and align vacuum filters	Vacuum Filter Area	"				
Lubricate chemical conditioning drums	Vacuum Filter Area	"				
Check, lubricate and adjust vacuum pumps	Vacuum Filter Area	"				
Check, lubricate and adjust filtrate pumps	Vacuum Filter Area	"				

Sheet 5 of 6

SUBSYSTEM DEWATERING SYSTEM

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL MAINTENANCE MECHANIC HIGH	 MED	 LOW
PREVENTIVE MAINTENANCE (continued)						
Check, lubricate and align belt conveyors	Belt Conveyor Area	Weekly	5 1/2 Hrs.			
Lubricate weightometer	" " "	"				
Check, lubricate and adjust sludge well air compressor	Sludge Pump Area	"				
Check, lubricate and adjust sludge pumps	" " "	"				
Clean coils of vacuum filters	Vacuum Filter Area	As Required	2 Weeks (every 4 months)			
Flush piping (sludge, filtrate, lime slurry)	--	As Required	1 Hour (every month)			
Clean Motor Control Panels	Control Panel Area	Monthly	6 Hours	MAINTENANCE ELECTRICIAN		
Check, lubricate, clean and adjust following Motors:		Monthly				
Sludge Pump	Sludge Pump Area					
Sludge Tank Agitator Air Compressor	" " "					
Lime Feeder	Lime Storage Area					
Lime Slaker	Lime Slaker Area					
Lime Slurry Pump	Lime Slurry Tank Area					
Lime Slurry Agitator	Lime Slurry Tank Area					
$FECL_3$ Pump	$FECL_3$ Tank Area					
Chemical Conditioning Mixer	Vacuum Filter Area					
Vacuum Filter	Vacuum Filter Area					
Belt Conveyor	Belt Conveyor Area					
Spray Water Pump	Vacuum Pump Area					
Filtrate Pump	" " "					
Vacuum Pump	" " "					

Sheet 6 of 6

SUBSYSTEM ANAEROBIC DIGESTER

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				SLUDGE-CONTROL OPERATOR		
				HIGH	MED	LOW
INSPECT AND RECORD						
Check meters and position of controls of motor control panel	Digester Bldg.	Every 2 hours	9 Mins.			
Check level of sludge in digester tanks	" "	" " "				
Check temperature gage and control settings of heat exchangers	" "	" " "				
Check operation of recirculation pumps of heat exchanger	" "	" " "				
Check operation of protected water system	" "	" " "				
Check level of supernatant	" "	" " "				
Check operation of sludge pumps	Digester Bldg. - Basement	" " "				
Inspect valves and piping for leakage	" " "	" " "				
SAMPLES						
None						
NORMAL OPERATIONS						
Start/stop sludge pumps	Motor Control Panel	Daily	3 Mins.			
Alternate protected water pumps	" " "	"				
Open/close valves	Digester Bldg. - Basement	As required	Approx. 15 Mins. Every 8 Hours			
Adjusts heat exchanger	Digester Bldg.	" "				
Transfer sludge	" "	" "				

Sheet 1 of 3

SUBSYSTEM ANAEROBIC DIGESTER

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				SLUDGE-CONTROL OPERATOR		
				HIGH	MED	LOW
NON-ROUTINE						
Power Interruption		Average 4 imes per year	4 Mins.		X	
Check operation of following equipment:	Digester Bldg.					
Recirculating Pumps	" "					
Protected Water Pumps	" "					
Heat Exchangers	" "					
Sludge Pumps	Digester Bldg.-Basement					
Restart above equipment if necessary						
Plugged Piping						
Open/close valves to isolate plugged line and reroute sludge or liquid being transferred.		Average of 15 occurrences per year	Average of 19 1/2 hrs. each occurrence. Involves maintenance personnel in addition to operator		X	
Start/stop pumps					X	
Remove flanges or sections of piping as necessary to gain access to plugged sections.					X	
Flush or rod-out plugged line.					X	

Sheet 2 of 3

SUBSYSTEM ANAEROBIC DIGESTER

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				SLUDGE-CONTROL OPERATOR		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE						
Replenish oil in oilers of sludge pumps	Digester Bldg. - Basement	As required	6 Mins.		X	
Tighten packing glands of pumps (sludge, protected water, recirculating)	" " "	As required			X	
				MAINTENANCE MECHANIC		
Check oil level, adjust packing glands, and lubricate sludge pumps	" " "	Weekly	45 Mins.			
Check oil level, adjust packing glands, and lubricate protected water pumps	Digester Bldg.	"				
Check oil level, adjust packing glands, and lubricate recirculating pumps	" "	"				
Clean strainer of sludge pump	Digester Bldg. - Basement	Monthly	- 5 Mins.			
				MAINTENANCE ELECTRICIAN		
Clean motor control panels	Digester Bldg.	"	1 Hour			
Check, lubricate, clean and adjust following motors:	" "	"				
Sludge pumps						
Recirculating pumps						
Protected water pumps						
Check, clean and adjust meters	" "	Quarterly	- 1 Hour			

Sheet 3 of 3

SUBSYSTEM INCINERATION AND ASH DISPOSAL

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				INCINERATOR OPERATOR		
				HIGH	MED	LOW
INSPECT AND RECORD						
Record following data for all operating furnaces: Temperature - Hearths 1 through 5 Temperature - Scrubbers, in and out Temperature - Cooling air Flow Rate - Furnace draft Flow Rate - Gas	Furnace Control Station	Hourly	16 Minutes			X
Record burner settings	Furnace - Main Floor	Hourly				X
Record filter cake accumulative reading and calculate tons/hour, recording same.	Weightometer Area	"				X
Check furnace flame in operating furnaces	Furnace - Main Floor	"				X
Check furnace shaft oilers	Furnace - Upper Level	"				X
Record water pressure to scrubber precoolers	Furnace - Upper Level	"				X
Check conveyor belt	Furnace - Upper Level	"				X
Record water supply pressure to scrubbers	Furnace - Main Floor	"				X
Check ash hearths	Furnace - Basement	"				X
Record pressure of ash hopper agitators	Furnace - Basement	"				X
Check service air compressor and check level of oil in oilers.	Furnace - Basement	"				X

Sheet 1 of 5

SUBSYSTEM INCINERATION AND ASH DISPOSAL

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				INCINERATOR OPERATOR		
				HIGH	MED	LOW
INSPECT AND RECORD (continued)						
Check ash slurry pumps (belts & glands)	Furnace - Basement	Hourly	↑			X
Check agitator pump	Furnace - Basement	"				X
Check scrubber pump	Furnace - Basement	"				X
Check spray water pump	Furnace - Basement	"				X
Record induced draft limit switch temperature	Furnace - Upper Level	Every 4 Hours	3 Minutes			X
Record amperage of induced blower fans	Motor Control Panel	Every 4 Hours				X
Check furnace drive shear pins	Furnace - Basement	Every 4 Hours				X
Check ash chute	Furnace - Basement	Every 4 Hours				X
Record spray wash pressure to induced draft blowers	Furnace - Basement	Every 8 Hours	3 Minutes			X
Measures calgon solution level and records	Furnace - Basement	Every 8 hours				X
Record reading on gas meter	Gas Meter Building	Daily	— 6 Minutes			X
SAMPLES						
Filter Cake (8 hour composite)	Conveyor Belt Area	Hourly	— 2 Minutes			X
NORMAL OPERATIONS						
Bleed water from filter of service air compressor	Furnace - Basement	Every 2 Hours	— 1 Minute			X
Clean basket screen filters in protected water system	Furnace - Basement	Every 8 Hours	— 2 Minutes			X
Clean basket strainers for scrubber pumps	Furnace - Basement	Every 48 Hours	— 2 Minutes			X

Sheet 2 of 5

SUBSYSTEM INCINERATION AND ASH DISPOSAL

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				INCINERATOR OPERATOR		
				HIGH	MED	LOW
NORMAL OPERATIONS (continued)						
Ignites additional burners or turns burners off	Furnace - Main Floor	As Required	Comprises an average of 12 mins. every 4 hrs.		X	
Adjust burners	Furnace - Main Floor	As Required			X	
NON-ROUTINE OPERATIONS						
Power Interruption						
Re-energize following equipment in sequence:			8 Minutes			
Protected water system	Motor Control Panel	Average of 4 times per year			X	
Sludge conveyors	" " "					
Scrubber water pumps	" " "					
Filter agitator pump	" " "					
Cooling Fans	" " "					
Turbo blowers	" " "					
Furnace drives	" " "					
Induced draft fans	" " "					
Ash hopper pump	" " "					
Spray water pump	" " "					
Energize maxon safety shut-off valve and relight burners	Furnace - Main Floor					
Check operation of above equipment and adjust accordingly						

Sheet 3 of 5

SUBSYSTEM INCINERATION AND ASH DISPOSAL

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				INCINERATOR OPERATOR		
				HIGH	MED	LOW
Conveyor Pulley Stoppage						
Inspect conveyor for cause of stoppage	Conveyor area	Average of 8 times a year	Comprises an average of 50 Mins. Operator Time		X	
Perform corrective action						
Shovel filter cake onto conveyor and clean up area						
Check operation of conveyor after re-energized by Filter Operator						
PREVENTIVE MAINTENANCE						
Fill oil reservoir of furnace shaft oilers	Furnace - Upper Level	Every 4 Hours or as Required	3 Minutes			X
Grease exhaust fan bearings on scrubber	Furnace - Upper Level	Daily	2 Minutes			X
				MAINTENANCE MECHANIC		
Check and lubricate scrubber damper	Furnace - Upper Level	Weekly	2 1/2 Hrs			
Check furnace shaft cooling air fans and grease bearings and adjust drive belt if necessary	Furnace - Basement	Weekly				
Inspect furnace drives, lubricate, and check drive belts, adjust as necessary	Furnace - Basement	Weekly				
Check oil level of furnace bottom bearing, replenish if necessary	Furnace - Basement	Weekly				
Inspect combustion air turbo blower	Furnace - Basement	Weekly				
Check and lubricate ash hopper make-up water valve	Furnace - Basement	Weekly				

SUBSYSTEM INCINERATION AND ASH DISPOSAL

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL		
				MAINTENANCE MECHANIC		
				HIGH	MED	LOW
PREVENTIVE MAINTENANCE -(continued)						
Check ash slurry pumps and replenish oil, adjust belt and packing if required.	Furnace - Basement	Weekly	↑			
Check, lubricate and adjust service air compressor	Furnace - Basement	Weekly				
Check protected water system	Furnace - Basement	Weekly				
Check city water system	Furnace - Basement	Weekly				
Inspect scrubber and agitator water pumps and adjust seal if necessary	Furnace - Basement	Weekly				
				MAINTENANCE ELECTRICIAN		
Clean Motor Control Panels	Control Panel Area	Monthly				
Check, lubricate, clean and adjust following motors:		Monthly				
Turbo blower Conveyors Service air compressor Ash slurry pumps Agitator pump Scrubber pump Spray water pump Inducer blower fans Furnace drive Protected water pumps			5 1/2 Hrs.			
Check, clean and adjust meters and recorders of furnace control panel. Replenish ink in recorder needles.	Furnace Control Station	Quarterly	30 Mins.			

Sheet 5 of 5

SUBSYSTEM CHLORINATION

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL UTILITIES OPERATOR HIGH	 MED	 LOW
INSPECT AND RECORD			3 Mins.			X
Check chlorine room for chlorine odor	Chlorine Room	Every 2 Hours				
Check operation of evaporators and record:		" " "				X
Final effluent flow (MGD) Chlorine flow rate (lbs/day) Residual chlorine (PPM)	Admin. Bldg.-Meter Room Chlorine Room " "	" " "				
Check and record scale weight of chlorine tank in use	Chlorine garage	" " "				X
SAMPLES						
Chlorine Residual:						
Final effluent - activated sludge Final effluent - Trickling Filter	A.S. Contact Tank T.F. Contact Tank	" " " " " "	2 Mins.			X
NORMAL OPERATIONS						
Determine chlorine residual - activated sludge	Aeration Bldg. - Lab	" " "	16 Mins.	X		
Determine chlorine residual - trickling filter	Trickling Filter Bldg.-Lab	" " "		X		
Adjust chlorine evaporators	Chlorine Room	As required	12 Mins.		X	
Replace chlorine tank and connect tank to system	Chlorine Garage	" "				X

Sheet 1 of 2

SUBSYSTEM CHLORINATION

FUNCTION	LOCATION	FREQUENCY	ESTIMATED TIME	SKILL UTILITIES OPERATOR HIGH	 MED	 LOW
NON-ROUTINE OPERATIONS						
Power Interruption						
Turn off chlorine flow at tank headers	Chlorine Garage	Average of 4 times per year	1 Min.			X
Turn on chlorine flow when H.P. final effluent pumps are operating	" "					
				MAINTENANCE ELECTRICIAN		
PREVENTIVE MAINTENANCE						
Check meters and recorders of following units:						
Chlorine residual	Chlorine Garage	Quarterly	30 Mins.			
Chlorine evaporators	" Room					
Chlorine gas detector	" "					
Chlorine flow	" "					
				MAINTENANCE MECHANIC		
Lubricate chain hoist	Chlorine Garage	"	3 Mins.			

Sheet 2 of 2

APPENDIX G

MALFUNCTION LOG
SEWAGE TREATMENT PLANT
FLINT, MICHIGAN

Item No.	Date	Equipment Description	Equipment Location	Work Order Written	Problem	Work Order Received	Date Started	Date Completed
1344	6/24/71	West Scum ejector	Grit Bldg.	Yes	Will not shut off	6/24/71	6/24/71	6/24/71
1345	6/24/71	#1 Lime pump	Inc.	Yes	Diaphragm ka-flooey	6/25/71	6/25/71	6/25/71
1346	6/25/71	#1 Filter	Inc.	Yes	Filtrate not being taken away (going up on roof)	6/25/71	6/25/71	6/25/71
1347	6/25/71	#3 Filtrate sample line	Inc	Yes	Plugged	6/25/71	6/25/71	6/25/71
1348	6/25/71	Raw Sewage Dip Stick	Grit	Yes	Needs repair	6/25/71	6/25/71	6/25/71
1349	6/25/71	M.L. Dip Stick	M.L. Channel	Yes	Needs repair	6/25/71	6/25/71	6/25/71
1350	6/25/71	#2 Filtrate Seal H_2O gage	Inc.	Yes	Not good	6/25/71	6/25/71	6/25/71
1351	6/25/71	Thickened Sludge Meter	Meter Rm.	Yes	Not working	6/25/71	6/28/71	6/28/71
1352	6/25/71	Scrubber Press Line	E Furnace	Yes	Broken wooden plug stuck in it	6/28/71	7/1/71	7/1/71
1353	6/25/71	East Furnace inspecion door	E Furnace	Yes	Inspection door hinge broken	6/28/71		
1354	6/26/71	#3 Filtrate pump	Inc.	Yes	Needs packing	6/28/71	6/28/71	6/28/71
1355	6/27/71	#2 Filter	Inc.	Yes	Remote switch on W. Wall	6/28/71	6/28/71	6/28/71
1356	6/27/71	#1 Filter filtrate	Inc.	Yes	Filtrate pump not pumping	6/28/71	6/28/71	6/28/71
1357	6/27/71	#3 Filter	Inc.	Yes	Time bar needs readjusting	6/28/71	7/1/71	7/1/71
1358	6/28/71	#2 Sludge pump	Inc.	Yes	Parking needs adjustment	6/28/71	6/29/71	6/29/71
1359	6/29/71	#3 Sludge pump	Inc.	Yes	Parking needs adjustment	6/30/71	6/30/71	6/30/71
1360	6/29/71	East scum ejector	Grit	Yes	Not working properly	6/30/71	6/30/71	6/30/71
1361	6/29/71	Thickened sludge	Meter	Yes	Still not working (meter)	6/30/71	6/30/71	6/30/71
1362	6/29/71	Waste sludge meter	Meter	Yes	Not working	6/30/71	6/30/71	6/30/71
1363	6/29/71	#1 Chlorinator	Cl_2 Bldg.	Yes	High gas temperature and pressure	6/30/71	6/30/71	6/30/71
1364	6/29/71	Truck		Yes	Broken left door handle	6/30/71	7/6/71	7/6/71
1365	6/30/71	#4 Conveyor	Inc. Bldg.	Yes	Holes in conveyor structure	7/1/71	7/2/71	
1366	6/30/71	Brady	Inc. Bldg.	Yes	Low level light sticking	7/1/71	7/1/71	7/1/71
1367	6/30/71	Hot water heater	Inc.	Yes	Needs a new thermocouple	7/1/71	7/1/71	7/1/71
1368	6/30/71	#2 Lime pump & #1	Inc.	Yes	Diaphragm	7/1/71	7/1/71	7/1/71
1369	7/1/71	Basket strainer	Inc.	Yes	Chamber valves not sealing	7/2/71	7/2/71	

EQUIPMENT MALFUNCTIONS SEWAGE TREATMENT PLANT

Sheet 1 of 2

SUBSYSTEM: Primary Treatment
ELEMENT: Pumping and Screening

Equipment Description	Quantity Installed	Failures	Malfunctions	Operating Hours	MTBF	MTBM
1100 /01 Raw sewage mains	2	0	0	17520	-	-
/02 Pump station wet well	1	0	0	8760		-
/03 Bar screen/rake	1	799(F) 1042(F) 1110(F) (4) 1170(F)	0	1460	365.0	-
/04 Sewage pumps and motors 14" pumps and electric motors (2) 12" pump and electric motor (1)	3	1191(F) 1246(F) (2)	744(M) 863(M) 932(M) 938(M) (6) 1221(M) 1389(M)	1752	8760	2920
/05 Pump motor controls Switching controls system	1	768(F) 785(F) (2)	754(M) 829(M) 879(M) (4) 1336(M)	8760	4380	2190
/06 Piping and check valves (with 14" pumps) Piping and check valve (with 12" pump)	3	Best Foremen's Est. 1 in 6 years	870(M) (1)	8760	52560	8760
/07 A. Flow meter and recorder	1	716(F) 1380(F) (2)	(0)	8760	4380	-
B. Instrument Air compressors	2	926(F) (1)	933(M) 939(M) (2)	8760	8760	4380
/10 Plant Influent mains	1	Best Foremen's Est. during 1 year period. (1)	0	8760	8760	-

FAILURES AND MALFUNCTIONS SUMMARY WORK SHEET Sheet 2 of 2

APPENDIX H

RELIABILITY AND MAINTAINABILITY DATA

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
											At Design Average Flow Rate (34 MGD)					
Equipment Description	Quantity Installed	Failures	Malfunctions	Operating Hours	MTBF	MTBM	Duty Cycle	Adjusted MTBF	Adjusted MTBM	Adjusted Failure Rate-λ	Quantity Required	Reliability	Composite λ(x10⁻³)	Composite MTBF	Equipment Repair Time (R_e)(Hours)	λ x R(x10⁻³)
11100 /01 Raw Sewage Mains	2	0	0	17520	-	-	1.00	-	-	-	2	1.000	-	-	-	-
/02 Pump Station Wet Well	1	0	0	8760	-	-	1.00	-	-	-	1	1.000	-	-	-	-
/03 A - Bar Screen	1	0	0	8760	-	-	1.00	-	-	-	1	1.000	-	-	-	-
B - Rake	1	4	0	1460	365.0	-	0.17	2147.1	-	0.466	1	0.715	0.466	2147.1	5	2.33
/04 Sewage Pumps and Motors	3	2	6	17520	8760.0	2920.0	1.00	8760.0	2920.0	0.133	2	0.750	0.0004	2500.0	13	0.005
/05 Wet well level sensor and pump motor control system	1	2	4	8760	4380.0	2190.0	1.00	4380.0	2190.0	0.228	1	0.849	0.228	4380.0	1	0.228
/06 Piping and check valves	3	1/6	1	8760	52560.0	8760.0	1.00	52560.0	8760.0	0.019	2	Included with /04			-	-
/07 A - Flow Meter and Recorder	1	2	0	8760	4330.0	-	1.00	4380.0	-	0.228	1	0.349	0.228	4380.0	2	0.456
B - Instrument Air Compressors	2	1	2	8760	8760.0	4380.0	1.00	8760.0	4380.0	0.114	1	0.993	0.007	143	5.5	0.038
/10 Plant Influent Main	1	1	0	8760	8760.0	-	1.00	8760.0	-	0.114	1	0.921	0.114	8760.0	3	0.342

Sheet 1 of 2

WASTE WATER TREATMENT PLANT
RELIABILITY AND MAINTAINABILITY DATA
PUMPING AND SCREENING
11100

CALCULATIONS

$$\mathrm{MTBF}_{11100} = \frac{1}{\lambda_{11100}}$$

$$\lambda_{11100} = \Sigma\lambda_{/01\cdots\cdot/n} = (0.466+0.0004+0.228+0.228+0.007+0.114)\mathrm{x}10^{-3}$$ (from column (14) on Sheet 1 of 2)

$$= 1.043\mathrm{x}10^{-3}$$

$$\mathrm{MTBF}_{11100} = \frac{1}{1.043\mathrm{x}10^{-3}}$$

$$= 958 \text{ Hours}$$

$$\mathrm{MTTR}_{11100} = \frac{\lambda_{/01}R_{e/01}+\lambda_{/02}R_{e/02}+\cdots\cdot\lambda_{/10}R_{e/10}}{\lambda_{/01}+\lambda_{/02}+\lambda_{/10}} = \frac{(2.33+.005+0.228+0.456+0.038+0.342)\mathrm{x}10^{-3}}{1.043\mathrm{x}10^{-3}}$$

(from columns (17) and (14) on Sheet 1 of 2)

$$= \frac{3.399\mathrm{x}10^{-3}}{1.043\mathrm{x}10^{-3}}$$

$$= 3.25 \text{ Hours}$$

$$A_{11100} = \frac{\mathrm{MTBF}_{11100}}{\mathrm{MTBF}_{11100}+\mathrm{MTTR}_{11100}} = \frac{958}{958+3.25} = \frac{958}{961.25}$$

$$A_{11100} = 0.996$$

WASTE WATER TREATMENT PLANT
MTBF, MTTR, AND AVAILABILITY CALCULATIONS
PUMPING AND SCREENING
11100
(Continued)

Sheet 2 of 2

APPENDIX I

FORMULAS AND APPROXIMATION FORMULAS FOR CALCULATING THE RELIABILITY OF REDUNDANT RELATIONSHIPS

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FORMULAS AND APPROXIMATION FORMULAS FOR CALCULATING THE RELIABILITY OF REDUNDANT RELATIONSHIPS

Operational Redundancy. Redundant units are operating when a failure to one or more units occurs. Units remaining, e.g., 1 of 2, are needed to sustain required system function.

	Formula	Approximation Formula
1 of 2	$2e^{-\lambda t} - e^{-2\lambda t}$	$e^{-(\lambda t)^2}$
1 of 3	$3e^{-\lambda t} - 3e^{-2\lambda t} + e^{-3\lambda t}$	$e^{-(\lambda t)^3}$
1 of 4	$4e^{-\lambda t} - 6e^{-2\lambda t} + 4e^{-3\lambda t} - e^{-4\lambda t}$	$e^{-(\lambda t)^4}$
1 of n	$\sum_{a=1}^{n} (-1)^{a+1} \binom{n}{a} e^{-a\lambda t}$	$e^{-(\lambda t)^n}$
2 of 3	$3e^{-2\lambda t} - e^{-3\lambda t}$	$e^{-3(\lambda t)^2}$
3 of 4	$4e^{-3\lambda t} - 3e^{-4\lambda t}$	$e^{-6(\lambda t)^2}$
n-1 of n	$ne^{-(n-1)(\lambda t)} - (n-1)e^{-n\lambda t}$	$e^{-\binom{n}{2}(\lambda t)^2}$
2 of 4	$3e^{-4\lambda t} - 8e^{-3\lambda t} + 6e^{-2\lambda t}$	$e^{-4(\lambda t)^3}$
3 of 5	$6e^{-5\lambda t} - 15e^{-4\lambda t} + 10e^{-3\lambda t}$	$e^{-10(\lambda t)^3}$
n-2 of n	$\sum_{a=0}^{2} (-1)^a \binom{n}{a} e^{-n\lambda t} + \sum_{a=1}^{2} (-1) \binom{n}{a} e^{-(n-1)\lambda t} + \binom{n}{2} e^{-(n-2)\lambda t}$	$e^{\binom{n}{3}(\lambda t)^3}$
m of n	$\left[\sum_{a=0}^{m} (-1)^a \binom{n}{a}\right] e^{-n\lambda t} + \left[\sum_{a=1}^{m} (-1)^a \binom{n}{a}\right] e^{-(n-1)(\lambda t)} + \ldots \left[\sum_{a=m}^{m} \binom{n}{a}\right] e^{-(n-m)(\lambda t)}$	$e^{-\binom{n}{m-1}(\lambda t)^{n-m+1}}$

Sheet 1 of 2

Standby Redundancy. A unit is in operation to provide required system funcion. Redundant unit (or units) is "standing by" to be turned on should the operating unit fail.

1 of 2	$e^{-\lambda t} + (\lambda t)e^{-\lambda t}$	$e^{-\frac{(\lambda t)^2}{2}}$
1 of 3	$e^{-\lambda t} + (\lambda t)e^{-\lambda t} + \frac{1}{2}(\lambda t)^2 e^{-\lambda t}$	$e^{\frac{-(\lambda t)^3}{2}}$
1 of n	$e^{-\lambda t} + (\lambda t)e^{-\lambda t} + \frac{1}{2}(\lambda t)^2 e^{-\lambda t}$ $+ \cdots \frac{1}{(n-1)!}(\lambda t)^{n-1} e^{-\lambda t}$	$e^{-\frac{(\lambda t)^3}{n!}}$

(1) Number of each unit which must be working to provide required system function.

(2) Approximation formulas should only be used when $\lambda t \leq 0.200$

(3) $\binom{n}{a} = \frac{n!}{a!(n-a)!} = \frac{n \cdot n-1 \cdot n-2 \cdot \cdots \cdot 1}{a \cdot a-1 \cdot \cdots \cdot 1(n-a \cdot n-a-1 \cdots 1)}$

APPENDIX J

AWT FUNCTIONAL STAGING DIAGRAMS

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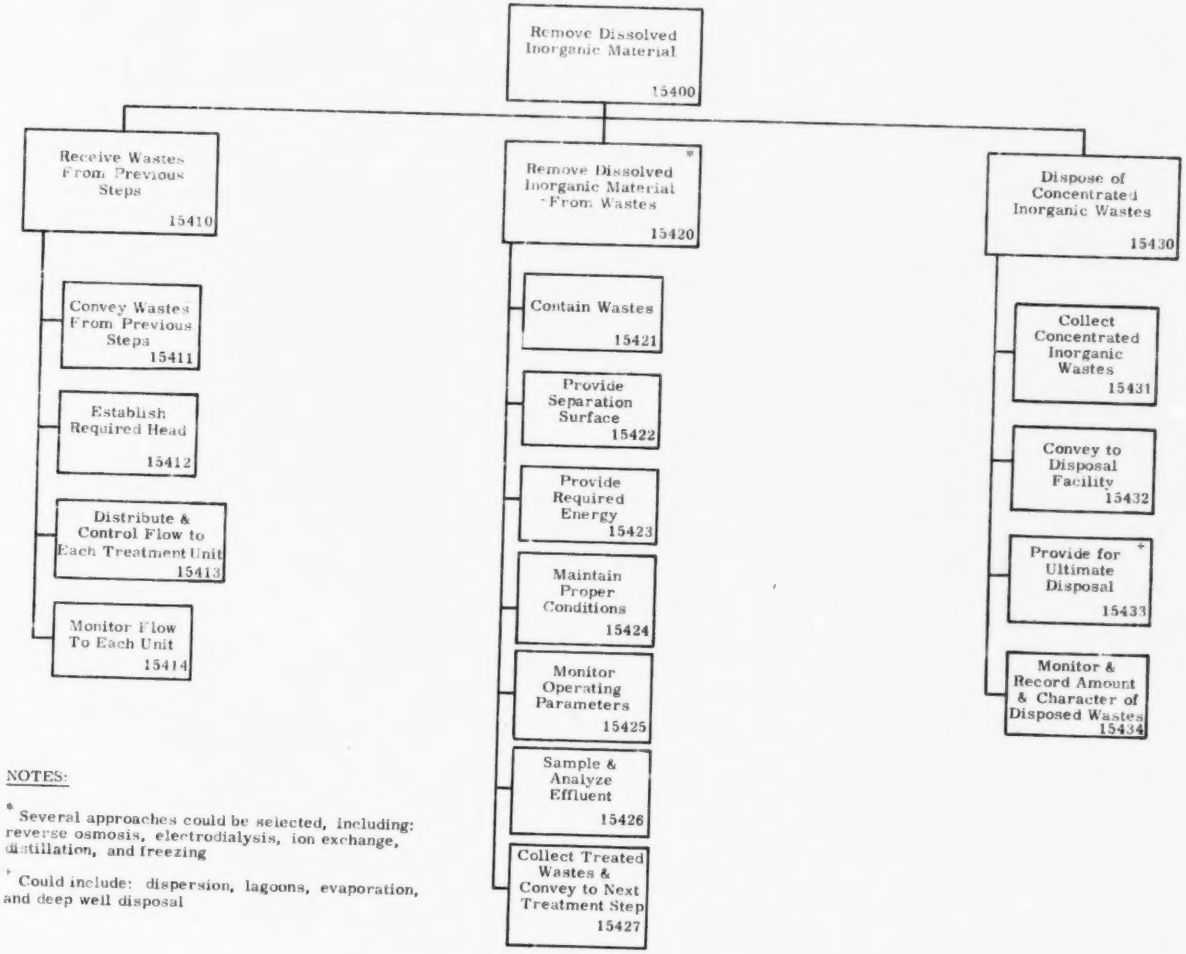
Remove Dissolved Inorganic Material 15400
Receive Wastes From Previous Steps 15410
Convey Wastes From Previous Steps 15411
Establish Required Head 15412
Distribute & Control Flow to Each Treatment Unit 15413
Monitor Flow To Each Unit 15414
Remove Dissolved Inorganic Material From Wastes * 15420
Contain Wastes 15421
Provide Separation Surface 15422
Provide Required Energy 15423
Maintain Proper Conditions 15424
Monitor Operating Parameters 15425
Sample & Analyze Effluent 15426
Collect Treated Wastes & Convey to Next Treatment Step 15427
Dispose of Concentrated Inorganic Wastes 15430
Collect Concentrated Inorganic Wastes 15431
Convey to Disposal Facility 15432
Provide for Ultimate Disposal + 15433
Monitor & Record Amount & Character of Disposed Wastes 15434

NOTES:

* Several approaches could be selected, including: reverse osmosis, electrodialysis, ion exchange, distillation, and freezing

+ Could include: dispersion, lagoons, evaporation, and deep well disposal

SAMPLE FUNCTIONAL STAGING DIAGRAM FOR ADVANCED WASTE TREATMENT

(sheet 1 of 3)

SAMPLE
SOUTH TAHOE PUBLIC UTILITY DISTRICT
WATER RENOVATION PLANT
MONTHLY SUMMARY
OF
FLOW AND LABORATORY DATA
FOR

____

FLOW DATA

Total Plant Flow for Month, MG ________
Average Daily Plant Flow for Month, MGD ________
Peak Flow Rate for Month, MGD ________
Total Flow for Month Into Indian Creek Res. MG ________
Total Flow for Month From Indian Creek Res. MG ________
Total Flow for Month From Pipeline Outlets, MG ________

WATER QUALITY DATA

Description	Requirements				Plant Performance		
		Lahontan R.W.Q.C.B. per cent of time			per cent of time		
	Alpine Co.	50	80	100	50	80	100
MBAS, mg/l, less than	0.5		0.5	1.0			
BOD, mg/l, less than	5		5	10			
COD, mg/l, less than	30		25	50			
Susp. S. mg/l, less than	2		2	4			
Turbidity JU,	5		5	10			
Phosphorus, mg/l less than	No	Requirements					
pH, units	6.5 to 8.5	6.5 to 9.0					
Coliform, MPN/100 ml	Adequately Disinfected	Median less than 2 Max. No. Consecutive Samples greater than 23, 2			Median ________ No. of Consecutive Samples greater than 23, ______		

(sheet 2 of 3)

M T W T F S S | D W M O SA A | J F M A M J J A S O N D | 1 2 3

DAYS OF WEEK | FREQUENCY | MONTH | SHIFT

Weekday of Month 1 2 3 4 5 | Assignment 1 2 3 4 5 | SPECIAL 1 2 3 4 5 6

INSPECTION AND SERVICE RECORD

Equipment Settled Sewage Channel

File No. 02-0028

Item	Work To Be Done	Ref.	Freq.	Time
1	Wash Down Channel.		D	
2	Remove & Reset all Slide Gates.		Q	

FILE NUMBER

4 3 2 1 | 0 1 2 4 7 SF | 0 1 2 4 7 SF | 0 1 2 4 7 SF | 0 1 2 4 7 SF

(sheet 3 of 3)